Consulting · Engineering · Implementation

IN ASSOCIATION WITH:

AFRICAN DEVELOPMENT BANK

ACTFCN

Project: Support to SE4ALL Country Actions processes in Ghana, Kenya and Tanzania

-Ghana-

Evaluation of the Financial and Economic Combination of SHS and Mini-Grid Systems

Date: July 24th 2015

ITP/UKP1205

Excellence in sustainable energy and climate change consulting




www.itpowergroup.com

Project: "Support to SE4ALL Country Actions processes in Ghana, Kenya and Tanzania"

Report: "Evaluation of the Financial and Economic Combination of SHS and Mini-Grid Systems"

Authors: Consortium formed by IT Power (UK) and AETS (France).

This report was written with support from the **African Climate Technology Finance Centre and Network (ACTFCN), African Development Bank and the Energy Commission of Ghana.**

African Development Bank

IT Power reference: UKP1205

Evaluation of the Financial and Economic Combination of SHS and Mini-Grid Systems

July 24th 2015

Contractor:

IT Power Consulting Ltd
St. Brandon's House
29 Great George Street
Bristol, BS1 5QT, UK
Tel: +44 117 214 0510
Fax: +44 117 214 0511
E-mail: itpower@itpower.co.uk
www.itpower.co.uk

Document control	
File path & name	Y:\Data\0WorkITP\0Projects\1205 ACTFCN SE4ALL Tanzania Kenya Ghana
Author	Akanksha Chaurey, Binu Parthan, David Fernandez, Yase Hage
Project Manager	Federico Fische
Approved	Akanksha Chaurey
Date	July 24th 2015
Distribution level	Client distribution

Template: ITP REPORT Form 005
Issue: 07; Date: 12/03/2012

EXECUTIVE SUMMARY

Ghana has made significant advancements in its SE4ALL initiative since its inception in 2012. In line with the three goals of the SE4ALL initiative, viz. ensure universal access to modern energy services, double the global rate of improvement in energy efficiency (EE) and double the share of renewable energy (RE) in the global energy mix, Ghana has set its country specific high impact goals, which it aims to achieve by the year 2020.

In Ghana, major progress has been made towards achieving its SE4ALL goal of universal electrification. The national electrification coverage stood at 76% as of January 2015 up from 67% in 2009 (Government of Ghana SE4ALL AA Summary, 2015). However, electrification in remote communities, especially those residing in areas that are difficult to access, faces great challenge due to the costs involved in extending the national grid into these communities. In order to overcome this challenge, the Government of Ghana (GoG) has set as a priority to provide universal access to electricity for Ghana's island and riverside communities by means of off-grid electrification interventions. This objective serves to fulfil the goal of not only ensuring universal electrification, but also increasing the productive use of energy (PUE) in both on and off-grid electrified communities through targeted interventions; universal access to electricity; and reaching 10% contribution of renewable energy in the electricity generation mix by 2020 from its current 0.3%, which is also part of Ghana's high impact SE4ALL objectives.

In line with the objectives of the assignment "Support for SE4ALL Country Actions processes in Ghana, Kenya and Tanzania" this report focuses on Ghana and presents (i) an evaluation of solar home systems (SHS) service models and financing modalities most appropriate to Ghanaian conditions and capabilities, (ii) an evaluation of the financial and economic costs and benefits of mini-grids for Ghana and (iii) an evaluation of the financial and economic combinations of SHS and mini-grid systems for household and PUE services relevant to Ghanaian circumstances. The outcomes of these three tasks provide the basis for developing a tool to assist the decision making for government and users for opting for combinations of SHS and mini-grid systems. The relationship between these three tasks is shown in Figure 1.

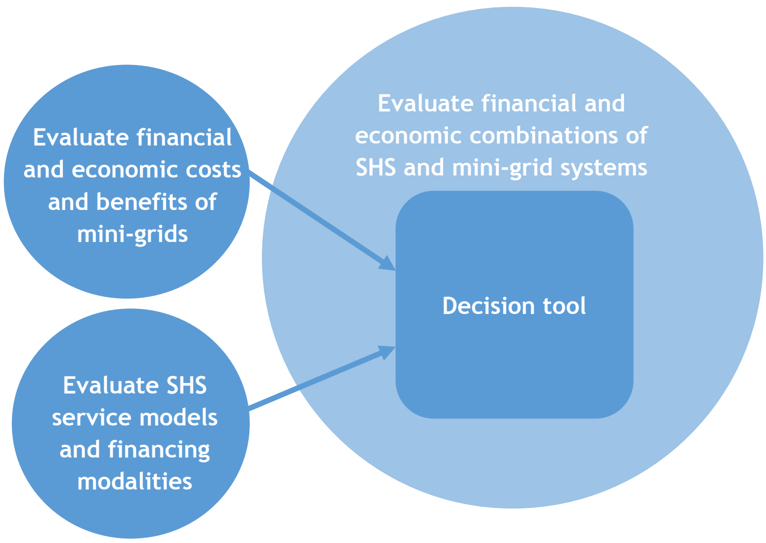


Figure 1 Evaluate financial and economic combinations of SHS and mini-grid systems

ABBREVIATIONS

AA	Action Agenda
BoG	Bank of Ghana
BOOM	Build-Own-Operate-Manage
BOM	Build-Own-Manage
BM	Build-Manage
CAP	Country Action Plan
CAPEX	Capital Expenditure
CU	Credit Union
CUA	Ghana Co-operative Credit Unions Association
DFCC	Development Finance Corporation of Ceylon
EC	Energy Commission
EDA	Energy Daily Allowance
EE	Energy Efficiency
ESD	Energy for Sustainable Development
FASL	First Allied Savings & Loans
FBE	Free Basic Electricity
GEDAP	Ghana Energy Development and Access Project
GEF	Global Environment Facility
GE/T/P	Green Empowerment/Tonibung/PACOS
GHI	Global Horizontal Solar Irradiation Level
GoG	Government of Ghana
GoK	Government of Kenya
HIO	High Impact Opportunities
HPS	Husk Power System
ICT	Information and Communication Technology
IDCOL	Infrastructure Development Company Ltd
IEA	International Energy Agency
INENSUS	Integrated Energy Supply Systems
IP	Investment Prospectus
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
JLG	Joint Liability Group
KES	KwaZulu Energy Services
KfW	Kreditanstalt für Wiederaufbau
LAU	Load Management and Accounting Unit
LCOE	Levelised Cost of Energy
LED	Light Emitting Diode

LPG	Liquefied Petroleum Gas
MCB	Miniature Circuit Breakers
MFI	Micro Finance Institution
MGP	Mera Gaon Power
MoP	Ministry of Power
MIX	Microfinance Information Exchange
MNO	Mobile Network Operators
MNRE	Ministry of New and Renewable Energy
MSME	Micro, Small and Medium Enterprises
NGO	Non-Government Organisation
NuRa	Nuon-RAPS
O&M	Operation and Maintenance
OASYS	Off-grid Access System
OISL	Opportunity International Savings and Loans
OPEX	Operating Expenditure
PAYG	Pay As You Go
PEG	Persistent Energy Ghana
PO	Partner Organisations
PPP	Public-Private Partnership
PUE	Productive Uses of Energy
PURC	Public Utilities Regulatory Commission
PV	Photovoltaic
RCB	Rural and Community Bank
RE	Renewable Energy
RES	Renewable Energy Systems
RESPRO	Renewable Energy Services Project
RETs	Renewable Energy Technologies
RRDP	Renewable Resources Development Project
SAT	Sinapi Aba Trust
SE4ALL	Sustainable Energy for All
SEEDS	Sarvodaya Economic Enterprises Development Services
SHS	Solar Home Systems
SREP	Scaling-up Renewable Energy Programme
SSA	Sub-Saharan Africa
SSP	SHS Service Providers
TERI	The Energy and Resources Institute
UNDP	United Nations Development Programme
VEC	Village Energy Committee

VPC	Village Power Committee
WBREDA	West Bengal Renewable Energy Development Agency

TABLE OF CONTENTS

1 CONTEXT & STRUCTURE OF THE REPORT

In 2012, the UN Secretary-General launched the Sustainable Energy for All (SE4ALL) initiative with three interlinked objectives to be achieved by 2030: ensure universal access to modern energy services, double the global rate of improvement in energy efficiency (EE) and double the share of renewable energy (RE) in the global energy mix.

Ghana was the first country to commit to the SE4ALL initiative. In 2012, Ghana released its first SE4ALL Country Action Plan (CAP) identifying the actions and the high impact interventions that the country has been undertaking towards the achievement of the three SE4ALL goals. Subsequently, with the support from the U.S. Department of State, an Investment Prospectus (IP) Framework was developed in December 2013 to guide Ghana's capacity to vet, update and prioritise potential investment opportunities in the priority areas. Ghana, during 2015, has been developing its SE4ALL Action Agenda (AA) based on the CAP 2012, and focuses on high impact opportunities and interventions that are highly likely to accelerate the pace of implementation of the country's SE4ALL goals. The AA would be followed by the development of SE4ALL IP with a view to mobilise the required investments for its implementation.

There has been great advancement in improving electricity access in Ghana. The national electrification coverage has seen an increase from 66.7% national coverage in 2008 (Ghana CAP, 2012) to 76% in January 2015 (Government of Ghana SE4ALL AA Summary, 2015). However, a large section of Ghana's remote population still remains un-electrified. Grid extension to these communities seem unlikely in the medium term or even long term due to the high costs involved, especially where the terrain is hostile and difficult to access such as in lakeside and island communities. As a result, the GoG has set providing access to electricity in these island and riverside communities as one of its priority SE4ALL objectives. Decentralised renewable energy systems (RES) including solar home systems (SHS) and mini-grid systems could provide a viable solution in these cases, especially due to the falling cost of generation using RE resources and also due to the abundance of RE resources, particularly solar, in Ghana. For instance, the typical cost of electrifying an island population by extending national grid with medium voltage submarine cables is 11 million USD compared with 1.2 million USD for installing a mini-grid[1]. The GoG has already demarcated the communities that would be served with off-grid electrification.

The use of SHS is prevalent in Ghana. There are numerous solar companies that sell and service SHS not only to off-grid communities, but also to on-grid sites for supplementing the grid power supply. Although the cost of electricity through solar photovoltaic (PV) systems is less than that of fossil fuel-based alternatives such as diesel *genset* (generation sets) and kerosene lamps over its life cycle, the high upfront cost of PV systems acts as a huge deterrent in its affordability to target users who hail typically from a remote/rural community. Appropriate service and financing models are vital to ensure successful deployment of SHS. There are various lessons to be learnt from the successes and failures of previous SHS programmes launched in Ghana as well as from the service and financing models of private sector companies. Moreover, best practices in SHS service models and financing schemes can be shared from successful experiences from other countries. An evaluation of these best practices and lessons from Ghanaian and global experience will be valuable in developing SHS service models and financing modalities to suit Ghanaian needs and capabilities. This evaluation is carried out in Chapter 2. This chapter first presents an overview of the present SHS market and financing situation in Ghana followed by evaluation of the past and existing financing and service models including both the government and private sector models in Ghana. Some of the outstanding models from other countries are also analysed. Based on lessons and inferences from all of the above, recommendations are made for SHS service models and financing modalities most appropriate to the country's capabilities and conditions.

In addition to SHS, Ghana is also looking at mini-grid options for providing energy access and for the PUE. The success of a mini-grid project depends a great deal on its delivery model. Ghana has very limited experience in mini-grids till date. However, there is abundant literature on mini-grids from the Sub-Saharan region and other global experience that can be contextualised for Ghana. Chapter

[1] Estimates were provided by the Ministry of Power during the Consultant's mission in February 2015

3 deals with evaluating the financial and economic costs and benefits of mini-grids by analysis global and regional best practices and lessons learnt, evaluating Ghanaian circumstances and then recommending mini-grid business models by contextualising best practises for Ghana specific conditions.

While both SHS and mini-grids have relevance in Ghana, their applicability and viability depends upon many factors such as geographical spread of the community, loads and demands, willingness and affordability to pay for services, among others. Besides, the criteria and benchmarks for applicability and viability vary from stakeholder to stakeholder. For instance, user would probably weigh the options on quality and cost of service while the project developer or the service provider would find return on investment or payback periods more relevant for a decision. Government, on the other hand, would be driven by the principles of equitability, judicious use of resources towards socio-economic growth of its communities. This necessitates a decision-making mechanism to investigate what circumstances dictate the suitability of SHS, mini-grid systems or a combination thereof for electrifying a particular community over other alternatives from the perspective of the government, project developer and the user. The decision making process entails evaluating a host of technical, financial and socio-economic aspects which can vary from region to region, in order to select the most appropriate off-grid system for that community including its business model, which is financially and economically viable. Thus Chapter 4 presents an evaluation of the financial and economic combination of SHS and mini-grid systems relevant to Ghana. The outcome of this interactive evaluation process is a flexible decision tool, in the form of a flow chart and qualitative/ quantitative matrices acceptable to Ghana which aims to aid the government, the users and the project developers, to arrive at an optimal off-grid RES system complete with its business model. This decision tool is presented in Section 4.4. This section explains step-wise, how to use the decision tool to arrive at appropriate technical and business model designs tailored to the necessity and conditions of the target community. The proposed business model framework draws heavily from the recommendations and suggestions on these models in Chapters 2 and 3.

2 EVALUATION OF SOLAR HOME SYSTEMS SERVICE MODELS AND FINANCING MODALITIES

2.1 Overview of present situation in Ghana

2.1.1 Status of SHS market industry in Ghana

Ghana receives high levels of solar insolation from 4.5 to 6.0 kWh/m^2/day (SE4ALL/ECREEE, 2014), which makes utilisation of solar energy attractive for rural and urban household level applications. Taking advantage of these abundant resources, SHS have been deployed in Ghana over the last 20 years through donor supported programmes in partnership with the GoG. These SHS programmes in Ghana have been supported by governments of Spain, Japan as well as the United Nations Development Programme (UNDP) and more recently the World Bank. It is estimated that through the government programmes, a total of over 21,600 SHS have been deployed in Ghana till the end of 2014[2]. In addition, there are private companies that operate outside the government programme selling SHS and offering SHS services. These private companies have together installed at least 50,000 SHS till early 2015[3].

It is evident from the consultations and questionnaire surveys conducted by the consultants that both the government and the industry see an important role for SHS in rural electrification of Ghana, especially where grid access[4] is not feasible in the near future[5]. The configuration of the SHS has also evolved over the years from large sized PV modules to smaller modules, change from fluorescent to solid state –Light Emitting Diode (LED) lighting, provision of mobile phone charging as a standard feature as well as portability/mobility. The prices for SHS components have also decreased considerably making the opportunity to deploy SHS even bigger. The GoG has set a target of deploying an additional 50,000 SHS under a new programme under development. The private sector companies also have large plans and aim to deploy additional 120,000 SHS[6] in the near term.

The Energy Commission (EC), the regulatory agency has licensed 11 renewable energy companies to install and maintain RES in Ghana, the vast majority of which are active in SHS markets through direct sales to the customer as well as operating under the government programmes. However, only a handful of companies are actively supplying SHS to Ghanaian households under the government programmes as well as based on private finance. The key private players in the SHS market are Azuri, Deng, Persistent Energy Ghana, Wilkins, Toyola etc. which together have the major share of SHS markets in Ghana.

2.1.2 Status of financial sector in Ghana

Ghana's financial sector is fairly well developed and in 2013, the domestic credit provided by all financial institutions was 34.8% of the GDP[7][8]. Ghana was also ranked at an impressive 36 out of 189 in the 'getting credit' criteria, which is considered as a yardstick for availability of finance for businesses of the ranking of 189 countries on their ease of doing business in 2015[9]. There are 30

---

[2] Including over 16,800 financed by GEDAP (including about 8000 lanterns) and over 4,800 from various other GoG programmes.

[3] 45,000 SHS by Azuri, 2000 SHS by Wilkins, 1000 by Deng, 1000 by PEG etc., based on data collected in a questionnaire survey administered by IT Power.

[4] Both national grid and isolated mini and micro-grids.

[5] Typically locations that will not be connected to the grid within 5 years of the proposed SHS installation.

[6] 100,000 from Azuri and 20,000 from PEG.

[7] World Bank, data.worldbank.org accessed in May 2015.

[8] Compared to 18.5% for Tanzania, 22.3% for Nigeria, 42.8% for Kenya and 182.2% for South Africa.

[9] World Bank Group's Doing Business 2015 Rankings www.doingbusiness.org accessed in May 2015.

banks[10] operating in Ghana licensed by Bank of Ghana (BoG)[11], of which 13 are subsidiaries of foreign banks and their market share is estimated at 51% (International Monetary Fund, 2011). Most of the banking sector branches and operations are concentrated in the urban areas of greater Accra, Ashanti and the eastern regions with limited presence in rural Ghana. Interest rates for debt denominated in GHS remain high at over 25%/year with the major component being the financial spread which was over 14%/year (Bank of Ghana, 2014). These high interest rates as well as other factors have contributed to relatively low uptake of financing by private sector and a limited role for financial sector in infrastructure financing in Ghana. The domestic credit to private sector was only 17% of GDP[12] and only 21.2% of businesses were using banks to finance their investments[13].

Ghana had a total of 311 licensed Micro Finance Institutions (MFIs) in late 2014[14]. According to Microfinance Information Exchange (MIX) a total of 3.1 million Ghanaian depositors were using MFIs and 630,338 were also borrowing funds with the total borrowing estimated at USD 745.5 million[15]. Ghanaian MFIs charge monthly interest rates ranging from 4% per month to 6.5% per month which translates to very high interest rates of 48 – 78%/year, often on a flat equated monthly payment[16] which further disadvantages the borrowers. The size of micro-finance loans range from GHS 50 to GHS 1000 with most in the range of GHS 100 to GHS 500, with typical tenure being 4 to 6 months (World Bank, 2010). Typically MFI loans are given to groups for micro and small income generating activities that typically revolve around agriculture and rural and cottage industries. The key players in the micro-finance sector in Ghana are the Sinapi Aba Trust (SAT), First Allied Savings & Loans (FASL), Opportunity International Savings and Loans – Ghana (OISL) and ASA Ghana.

Ghana also has an informal and unregulated savings collection system called *Susu*, where a *Susu* collector, collects savings from households on a daily basis and charges a commission for the collection. The households can then demand money back when a particular need arises and will demand their savings back after deducting a commission. Susu accounts are maintained with Rural and Community Banks (RCBs) which have a large rural presence. Susu loans are also offered by RCBs and MFIs for individuals who maintain a Susu account after completing a minimum period of deposits, typically 3 months. It is estimated that there are over 4000 Susu collectors active in Ghana (MF Transparency, 2012). The Susu collectors play an important role from a financial inclusion perspective as their outreach to clients, especially rural clients is more than double of that all the other organised financial channels combined. In 2007, the reach of the Susu collectors was 1.2 million compared to 0.3 million by credit unions and 0.1 by RCBs, which were the next best financing channels (World Bank, 2010).

Ghana also had a long history of credit unions (CUs) since 1955 when the first credit union was established at Jirapa in the Upper West Region. Ghana currently has 451 CUs with about 200 of them concentrated in Accra and Ashanti regions (Ghana Cooperative Credit Unions Association, Data on Credit Unions for 2013). CUs are in essence a credit co-operative and encourages its members to save on a regular basis and the resources so pooled together is available to the members at a lower than commercial interest rates. The CUs in Ghana are regulated by Ghana Co-operative Credit Unions Association (CUA) on behalf of BoG. The CUs had more than 0.5 million members and had asset base of over GHS 620 million (Ghana Cooperative Credit Unions Association, Data on Credit Unions for 2013). CUs suffer from a low level of loan repayment rate of 31% and very low rate of returns on assets of 10% (Ghana Cooperative Credit Unions Association, Data on Credit Unions for 2013).

[10] 27 banks and the ARB Apex Bank and two international banks which have representative offices.

[11] Bank of Ghana, www.bog.gov.gh accessed in May 2015.

[12] Compared to 12.6% for Nigeria, 13.1% for Tanzania, 31.6% for Kenya and 149.5% for South Africa.

[13] World Bank, data.worldbank.org accessed in May 2015.

[14] Bank of Ghana, 2014, List of Micro-finance institutions as of October 2014.

[15] MIX Market, Ghana Country Profile www.mixmarket.org accessed in May 2015.

[16] The interest rate is charged on the full loan amount, irrespective of the monthly repayments whereas the banking and financial sector only charges interest rates only on the outstanding loan amount.

There are a total of 137 RCBs active in Ghana (Bank of Ghana, 2013) which had assets of GHS 1.9 billion which represent 3.9% of the total banking system assets (Bank of Ghana, 2014). The RCBs are the largest providers of formal and regulated financial services in rural Ghana (World Bank, 2010). However RCBs are relatively small financial institutions with average asset base of GHS 3.8 million and are fully owned and governed by the communities in which they operate (World Bank, 2010). However the majority, 66%, of the RCBs are located in the four regions of Ashanti, Central, Eastern and Brong Ahafo. The RCBs offer savings deposits, loans for agricultural, commercial and personal needs as well as domestic and international money transfer services[17].

The ARB Apex Bank was established as a public limited liability company with the rural banks as its shareholders and started operations in 2002. ARB Apex Bank was established to provide financial, management and technical support to the RCBs and currently provides treasury management, check clearance, international and domestic funds transfer, computerisation, resource mobilisation as well as training and inspection.

Ghana has a high level of mobile phone penetration and had a total of more than 31 million mobile phone subscribers in early 2015[18] much more than its population of 25.9 million. All the major Mobile Network Operators (MNOs) in Ghana – MTN, Vodafone, Tigo and Airtel offer proprietary mobile money services. However regulatory constraints and limited acceptance by vendors etc. have limited the penetration of mobile money in the financial services market. Mobile money transactions in Ghana are estimated to be only less than 0.6%[19] of total financial services market of USD 110 billion. This translates to USD 6.4 Billion transacted through mobile money transactions in Ghana (Mondato, 2015). However the major MNOs are reporting regular increases in update of mobile money subscriptions and services and the role of mobile money is expected to increase in the future.

2.2 Current and past models for SHS service

2.2.1 Government SHS programmes

In a departure from traditional SHS finance and service models coordinated by governments, the programmes in Ghana have been service oriented. The Spanish government supported a programme in the late 90s with an outlay of about EUR 5 million and was aimed at installing 3,000 systems and collected a monthly service fee which amounted to twice the tariff paid by comparable rural households having access to grid electricity. However, in the case of the Japanese government programme, which targeted public facilities (such as schools, hospitals, health posts etc.), SHS were installed in the public facilities and at the employee quarters but did not collect monthly payments consistent with the government practice of not charging public facilities for electricity supplies.

The UNDP's Renewable Energy Services Project (RESPRO) initiative that operated from 1999 to 2003, with a financial outlay of USD 2.4 million, continued with the approach of monthly service fee payments by households and supported an installation of 1,800 SHS. Under RESPRO the service fee payments were 3 times the amount which would have been paid by the served households if they had access to grid electricity. However, the service payments under both Spanish and UNDP programmes, while considerably higher by a factor of 2 or 3 from electricity tariffs, were still unable to finance the cost of battery replacements at the end of life of the batteries around the 5th year. So while this approach by the GoG was ahead of the curve in terms of finance and business models in the same period in other parts of the world, it was not sustainable in the long run. Nevertheless, the principles of service delivery and cost recovery that were followed continue to remain valid today. The role of the private sector in these government SHS programmes was limited to supply of equipment and the finances for the SHS came from donor governments or the Global Environment Facility (GEF). The financial sector in Ghana also did not have any significant role in

---

[17] Through the ARB Apex Bank

[18] National Communications Authority www.nca.org.gh accessed in May, 2015

[19] Compared to 42% in Tanzania

the financing arrangements. The service model and financing arrangements under the government SHS programmes are illustrated in Figure 2.

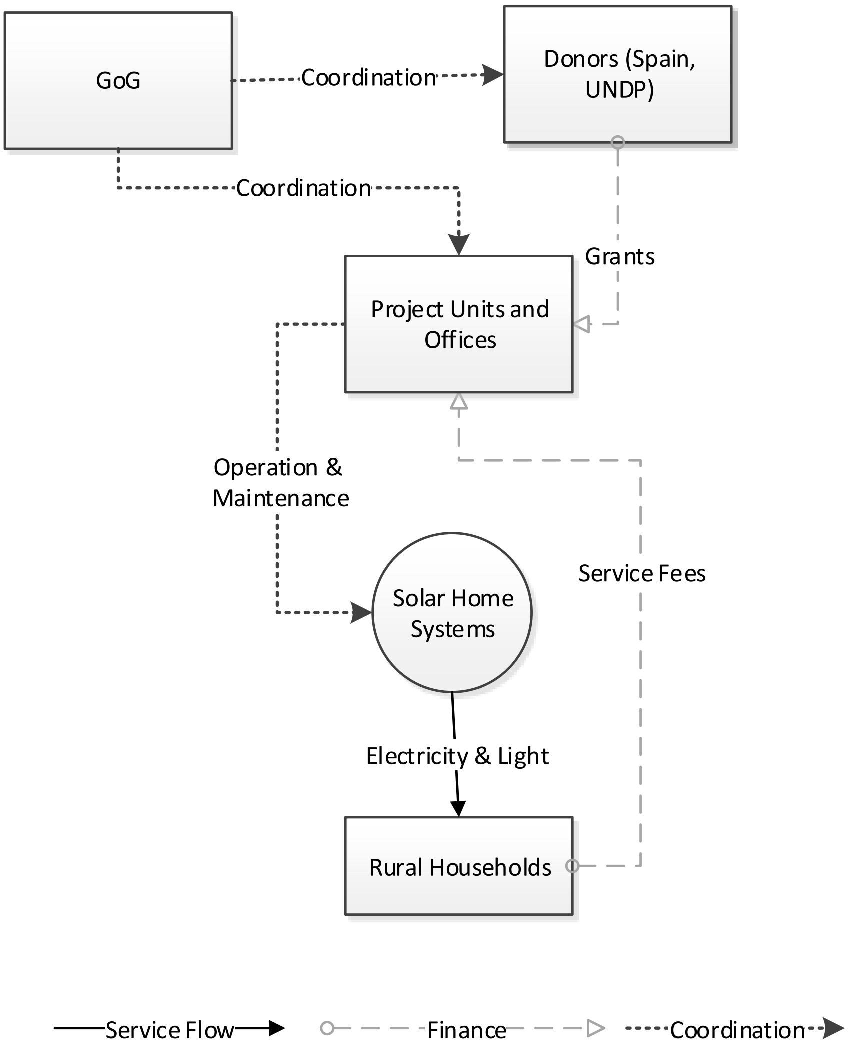


Figure 2 Service model and financing arrangements under government programmes

The sustainability of the service arrangements was also constrained by the continued service payments. As the system performance was affected by the failure of the service payments to cover replacement of batteries, this resulted in insufficient levels of service payments and eventual failure of the systems.

2.2.2 GEDAP model

The Ghana Energy Development and Access Project (GEDAP) built on the lessons from the UNDP and the Spanish government supported projects in the past and built a financing and service model that had the rural banking system at its core. The GEDAP was implemented through the ARB Apex Bank and its RCB members. The project started operating in 2009 in 11 selected districts in Ghana targeting households which were not planned to be electrified in the succeeding 5-10 years (ARB Apex Bank, Ghana Energy Development and Access Project, Solar Home Systems Project: Completion Report). The GEDAP was financed by the GEF and the World Bank and was implemented through active involvement of the private sector and RCBs.

The project which operated from 2009 to 2013 succeeded in supporting the installation of 16,822 systems in rural Ghana. The GEDAP was able to partner with 12 RCBs and 7 private RE companies in implementing the programme. The major RCB partners in terms of the volume of credit intermediated were RCBs in East Mamprusi, Sissala, Naara and Builsa (ARB Apex Bank, Ghana Energy Development and Access Project, Solar Home Systems Project: Completion Report). The Major Private sector SHS companies in terms of market share were Wilkins, Deng and Toyola (ARB Apex Bank, Ghana Energy Development and Access Project, Solar Home Systems Project: Completion Report). The project used a combination of loans and grants to make the SHS accessible to the rural households and insisted on a financial contribution from the user as well.

The financing and service modalities that were employed by GEDAP were as follows. All the systems were provided by the manufacturers including the cost of installation and a three year service. The households were able to purchase the system from any of the 7 manufacturers that were qualified to supply the systems. All the households that purchased the system with a service contract received a grant which subsidised the system costs in the range of 30-50% considering the economic criteria and poverty indicators of the household. The households then had to make a 10% margin contribution of the subsidised cost of the system as equity. 90% of the subsidised cost of the system was financed by the RCB at an interest rate of 28%/year for a loan tenure ranging from 1 year to 3 years with a moratorium of 6 months (ARB Apex Bank, Ghana Energy Development and Access Project, Solar Home Systems Project: Completion Report). 80% of these loan amounts extended by the RCBs were refinanced by the ARB Apex Bank using low cost financial resources made available through the World Bank. The ARB Apex bank hired solar project officers who facilitated credit appraisals, collection of repayments and minor maintenance.

The results of GEDAP have largely been positive from a financing perspective. It also familiarised and built capacity within the RCB ecosystem to finance SHS. This capacity is available for leverage by future programs. GEDAP has established a market led process where some SHS manufacturers and RCBs have done better business than other participants. GEDAP also introduced margin money contributions from the users and involved the users in end-user credit schemes based on cost recovery principles. The recovery rates by RCBs for end-user loans have varied from 100% to 56% of recoverables and there were cases of some private SHS suppliers not providing proper service as well as users tampering with the systems. Still, such aberrations are considered normal in such pilot innovation models. GEDAP is considered to provide another stepping stone in the evolution of SHS financing in Ghana. The service model and financing arrangements under the GEDAP model is illustrated in Figure 3.

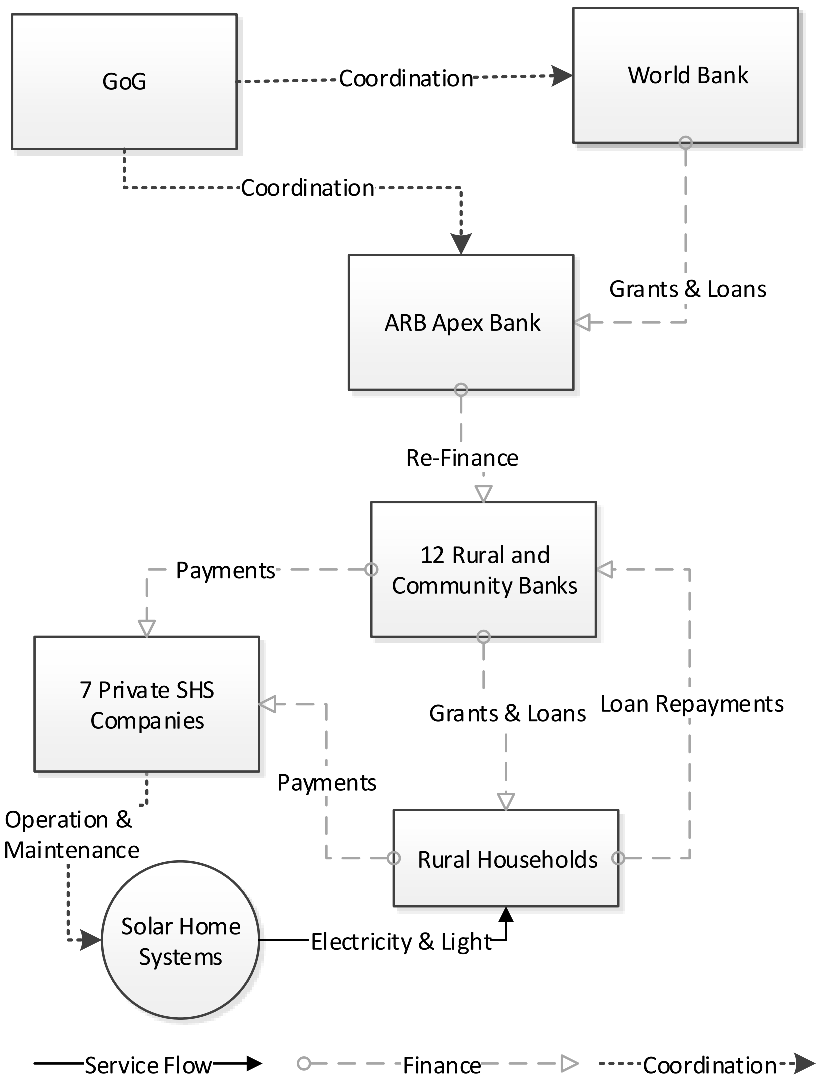


Figure 3 Service model and financing arrangements under GEDAP

2.2.3 Pay As You Go models

In the recent years, with the reduction in the cost of system prices and with low power consuming LED lights, the system sizes and prices have reduced considerably making SHS more a standardised product. Taking advantage of the reduction in prices and standard configurations, several companies in Ghana and elsewhere are offering Pay As You Go (PAYG) models for SHS. This service and finance model is being offered by at least two companies – Azuri Technologies and Persistent Energy Ghana (PEG) in Ghana and over 46,000 systems[20] have been provided to customers on a PAYG basis. As noted earlier, both companies are planning to sell and service an additional 120,000 systems in the next two years. Both companies are doing this market development and deployment with private capital and do coordinate with the government.

While the specifics of both companies' products vary, they both offer a small PV panel of 8 to 10 Wp with 2 to 4 LED lamps and a cell phone charger. Both companies charge the user an upfront fee of GHS 99 for PEG and USD 10 for Azuri, and the user then makes daily or weekly payments to continue to use the system. After a pre-determined period – 1 year in case of PEG and 2 years in the case of Azuri, the system is either fully owned by the user or the user can upgrade the system

[20] 45,000 by Azuri and 1000 by PEG.

and continue to pay the same periodic contributions. PEG requires a higher upfront contribution from the user and requires daily payments by the user using mobile money but the payments only last for one year before the ownership is transferred to the user. In contrast, Azuri has lower entry costs and weekly payments using a scratch card system where the user needs to punch in the code. The commitment period is also longer at 2 years for Azuri. The lower entry costs and the smaller payments and longer tenure seem to have attracted a larger number of user base for Azuri.

In terms of finance, Azuri has financed its operations and growth so far from own equity and partner resources and has not accessed other forms of financing. PEG accesses loans from banks to finance the systems for end-users and repays the bank from the user payments. The service and finance details of the PAYG models in Ghana are shown in Figure 4.

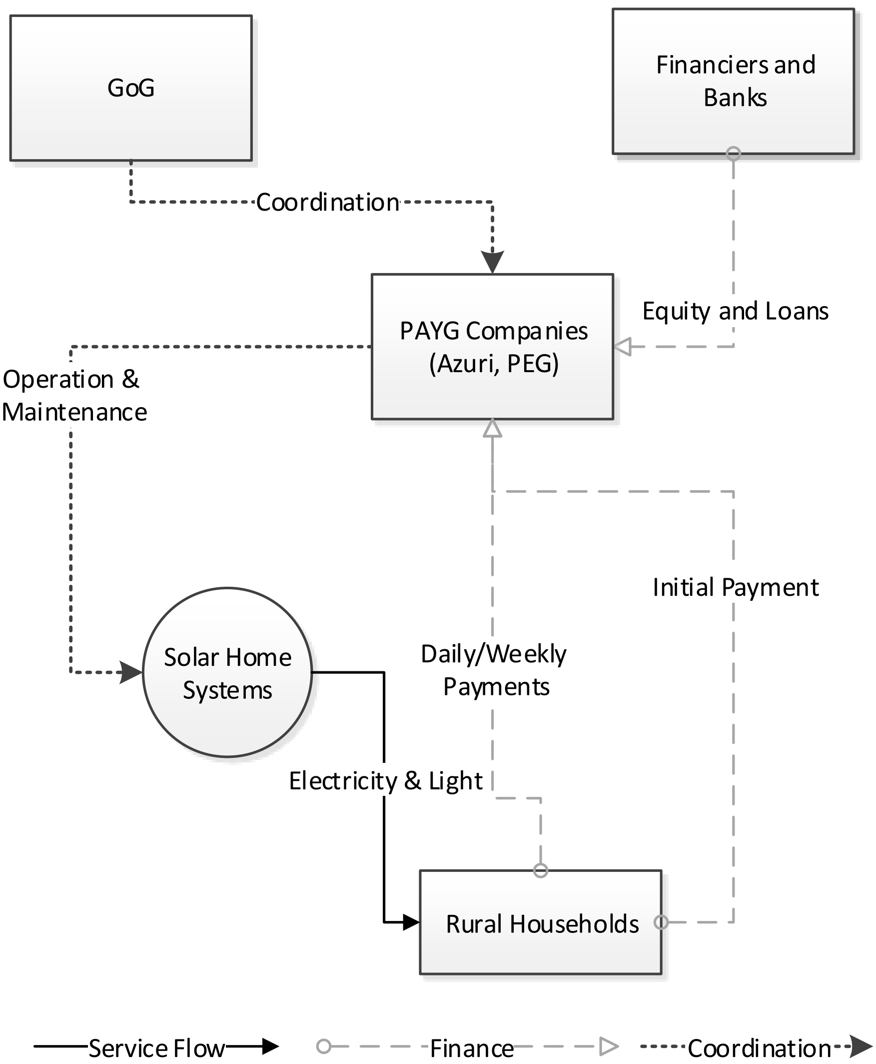


Figure 4 Service model and financing arrangements under PAYG models in Ghana

There is limited role for the government in the system apart from its regulatory, quality assurance and taxation role. The relative success of the PAYG schemes in Ghana and elsewhere in Sub-Saharan African (SSA) indicates that these systems are being offered at price points and payment frequencies that are comparable to that of kerosene purchases and kerosene lamps that they replace. If a future financing framework and government programmes could co-exist and supplement the private sector led PAYG models, Ghana will be able to reach its goal of universal electrification earlier than targeted.

2.2.4 Other models

The other SHS service model that is prevalent in Ghana is the outright purchase model which is being offered by major manufacturers such as Wilkins, Deng, PEG etc. In such cases the customer either pays the costs upfront for the whole system or pay 60% upfront and given a 40% credit by the manufacturers to pay within 6 months. Many of the systems purchased outright are large systems and are also used for powering TVs and efficient refrigerators. This market also extends into the electrified areas in Ghana and people purchase such systems as a back-up due to rolling black-outs prevalent in electrified areas. The outright purchase model is illustrated in Figure 5.

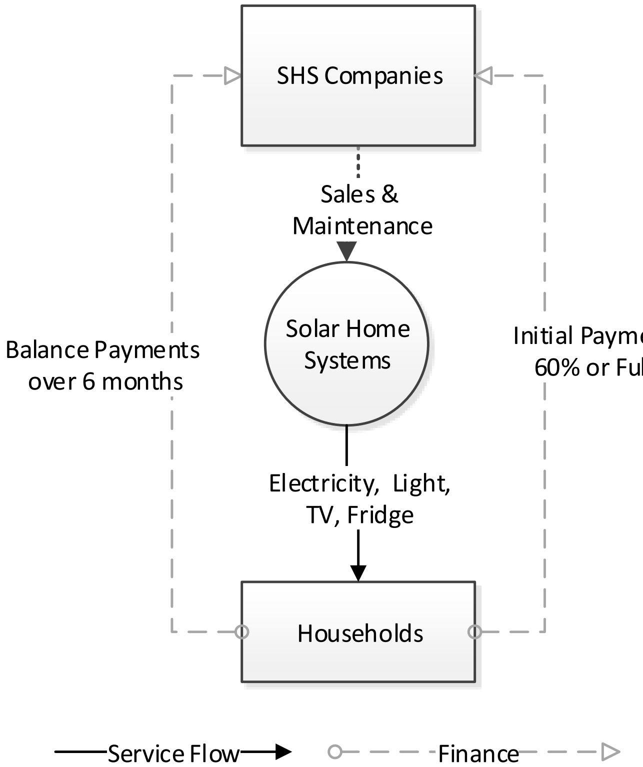


Figure 5 Service model and financing arrangements direct sales of SHS

Other models that are being used include the Energy Kiosk model which is used in Ghana by Non-Government Organisations (NGOs) such as empower playgrounds and also proposed by companies such as Weldy-Lamont. In such models the Energy Kiosk or a trailer act in a similar manner and offers charging services for a fee to the households which physically carry a portable battery to the centrally located kiosk for re-charging. These models have had limited penetration in Ghana and have service and financing arrangements similar to the PAYG systems although the user owns part of the system and the PV generator remains centralised. The Kiosk model is shown in Figure 6.

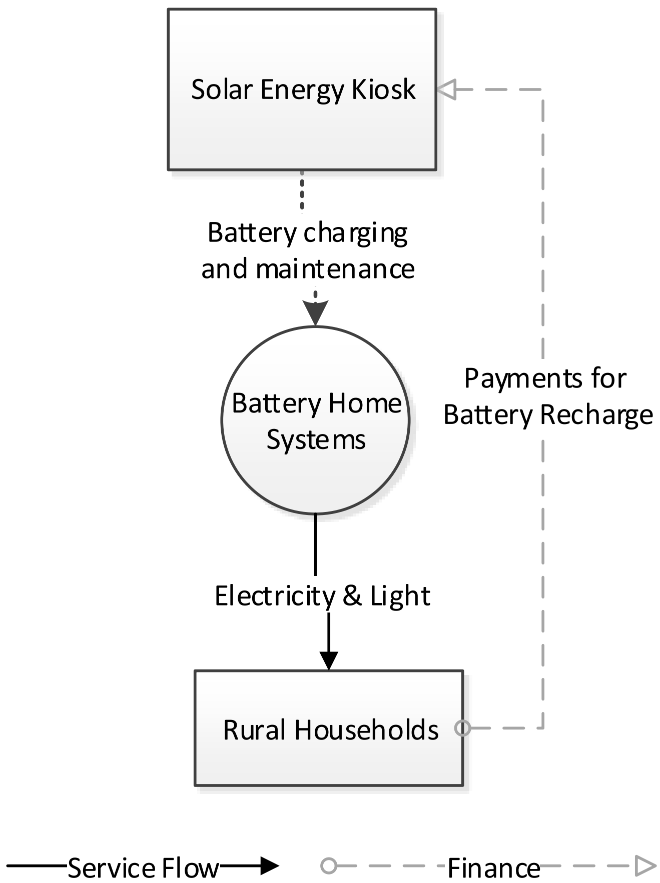


Figure 6 Service model and financing arrangements for energy kiosk models in Ghana

2.3 Global SHS service models and financing modalities

As noted earlier, SHS finance and service models in Ghana have generally been progressive and key sustainability principles were enshrined in government programmes. The private sector led PAYG, outright sales and energy kiosk models being implemented in Ghana are similar to models prevalent elsewhere such as the M-Kopa model in Kenya and the Energy Kiosks model in Malawi. However there maybe few models from Southern Africa and South Asia considered as outstanding, which may offer interesting elements of sustainability that are relevant to Ghana. These models are described below.

2.3.1 Mobile Network Operator model

Some MNOs are actively involved in a PAYG type arrangement as an add-on to the basic mobile subscription plan they offer to customers. A unique model in this regard is operated by Econet Wireless in Zimbabwe, South Africa and Lesotho in Southern Africa. The model is similar to the PAYG models used in Ghana by Azuri and PEG but the SHS is larger with various additional optional accessories and there is also a smaller upfront payment for the system. The payments are daily and the system ownership and the maintenance responsibility remains with the MNO. The system offered by Econet – A Home Power system consists of four charging points to charge wireless LED lamp, LED candles and mobile phones. There are also options for the users to procure additional accessories such as fans/ventilators, radios, TVs, mosquito repellents etc. along with the SHS.

The requirement for obtaining a home power system is an existing mobile telephone subscription with Econet and a minimum usage history. Econet is able to assess the creditworthiness of a prospective customer for the SHS based on the past usage and recharging history of the mobile telephone subscriber. There is an initial deposit of USD 10 to be made for the basic system and once the system has been installed at the household and the usage starts a service fee is deducted every day from them credit balance of the subscriber. For basic systems with 4 LED lamps the daily fees paid is as low as GHS 10 and the payments continue as long as the subscriber uses the system. The small and insignificant credit deductions on a daily basis which is probably the lowest payment anywhere for SHS, is lower than the expenditure on kerosene and candles by households. Due to the very long tenure over which the payments are spread, the household will make considerable savings on kerosene expenditure. The system is already installed in 2,000 households in southern Africa and Econet is targeting an additional 125,000 homes. This model is relevant to Ghana considering its strong MNOs, mobile subscriber base and the low payment, longer tenure model with low entry costs that have been successfully promoted by Azuri. However for such a model to be implemented in Ghana active participation by one or more MNOs in Ghana is needed. The MNO model is illustrated in Figure 7

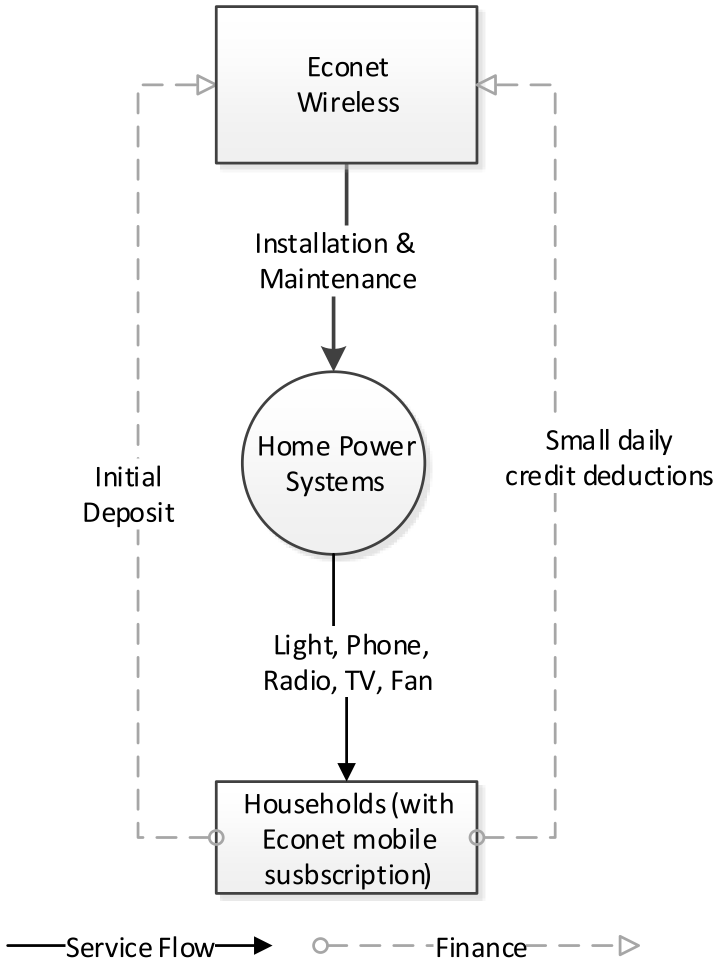


Figure 7 Service model and financing arrangements for Mobile Network Operator models in Southern Africa

2.3.2 SHS Concession Programme in South Africa

In 2001, South Africa awarded solar energy concessions to private SHS companies as service providers in the provinces of KwaZulu Natal, Limpompo and Eastern Cape in South Africa. The companies were selected through a competitive process of an open call for proposals and evaluation process in which a large number of interested companies participated. The selected companies were awarded exclusive rights to operate and provide off-grid SHS services in specific geographic locations and in these areas they had exclusive access to the various financial incentives and subsidies of the off-grid electrification programme provided by the South African Government.

The SHS service providers (SSP) Nuon-RAPS utility (NuRa), KwaZulu Energy Services (KES) and Solar Vision installed 46,000 SHS among them in the allocated concession areas (Restio Energy, 2014).

The average system had a 50 Wp PV Panel, 4 lights, electricity and mobile phone charging outlets and had to conform to the relevant South African national standard (Restio Energy, 2014). The South African government provided 80% of the SHS costs based on regulated price points as a subsidy to the SSPs. The SSPs where allowed to charge a connection fee from the households in a manner similar to what was being charged by the national utility. Thereafter the households do pay a regulated tariff which also included the maintenance and replacement of system components, including the batteries. In several municipalities the monthly fees are subsidised by the municipalities through a Free Basic Electricity (FBE) grant, which reduces the payments by users and provides the SSPs, a single point payment for a large portion of their revenue. International donors such as Norad, Kreditanstalt für Wiederaufbau (KfW) have supported capacity building and facilitation costs. SSPs such as KES and NuRa have also augmented their business models to sell Liquefied Petroleum Gas (LPG) alongside SHS services addressing both the thermal and electrical energy needs.

The SHS have been providing the intended service overseen by the SSPs for the last 15 years and a second similar concession of 29,000 has since been awarded in Eastern Cape to KES. The South African National Electrification Roadmap envisages an additional 250,000 to 300,000 households to be provided SHS services in a similar manner (Restio Energy, 2014). The implementation of the SHS concessions in South Africa require facilitating regulatory and policy frameworks as well as active involvement by the government, regulator and the national utility in the planning, selection and oversight of implementation. Thereafter, the programmes are considered scalable. The implementation arrangement for the SHS concession programme in South Africa is shown in Figure 8.

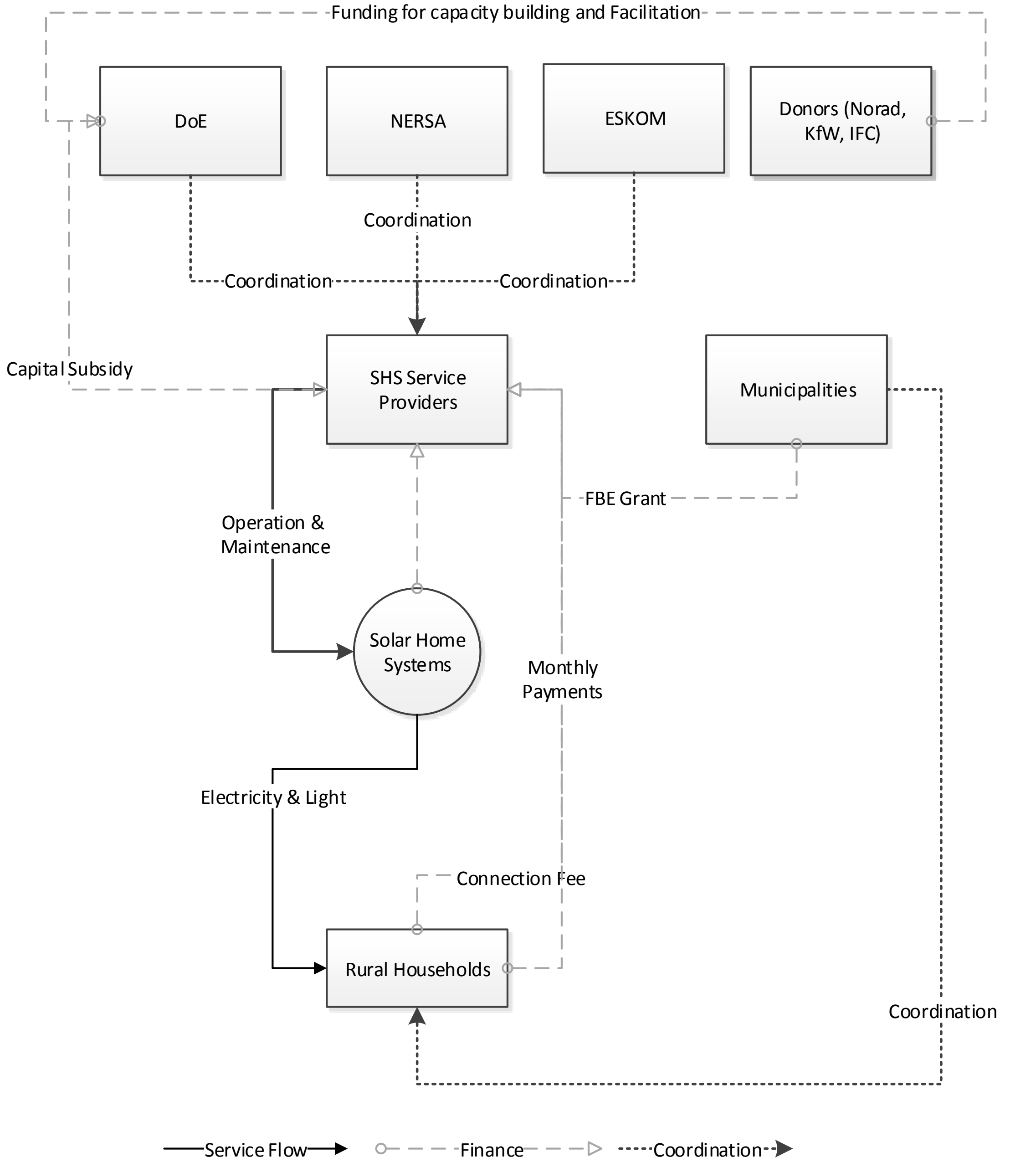


Figure 8 Service model and financing arrangements for SHS concessions in South Africa

2.3.3 SHS Finance Programmes in South Asia

Financing programmes for SHS was pioneered in South Asia in 1993 by the World Bank under the Renewable Resources Development Project (RRDP) in collaboration with the Indian Renewable Energy Development Agency (IREDA). Under the programme IREDA empanelled financial intermediaries which channel financing to end-users who purchase SHS. The financing arrangements provided for soft loans to be provided to intermediaries with an interest subsidy allowed for lending below the market rates. The financial intermediaries passed on the benefit of accelerated depreciation available for SHS to subsidise the capital cost of the SHS and offered the SHS as lease to the users. The SHS was supplied by suppliers that were empanelled by IREDA based on a pre-qualification process, which emphasised quality of product and management capability. The ownership of the system was retained by the financial intermediary during the lease period after which the ownership of the system was transferred to the rural household. The combined effect of the soft loans and accelerated depreciation benefits resulted in considerable reduction in the cost of SHS and reduced lease-rentals which made the systems more accessible to rural households. The model is illustrated in Figure 9.

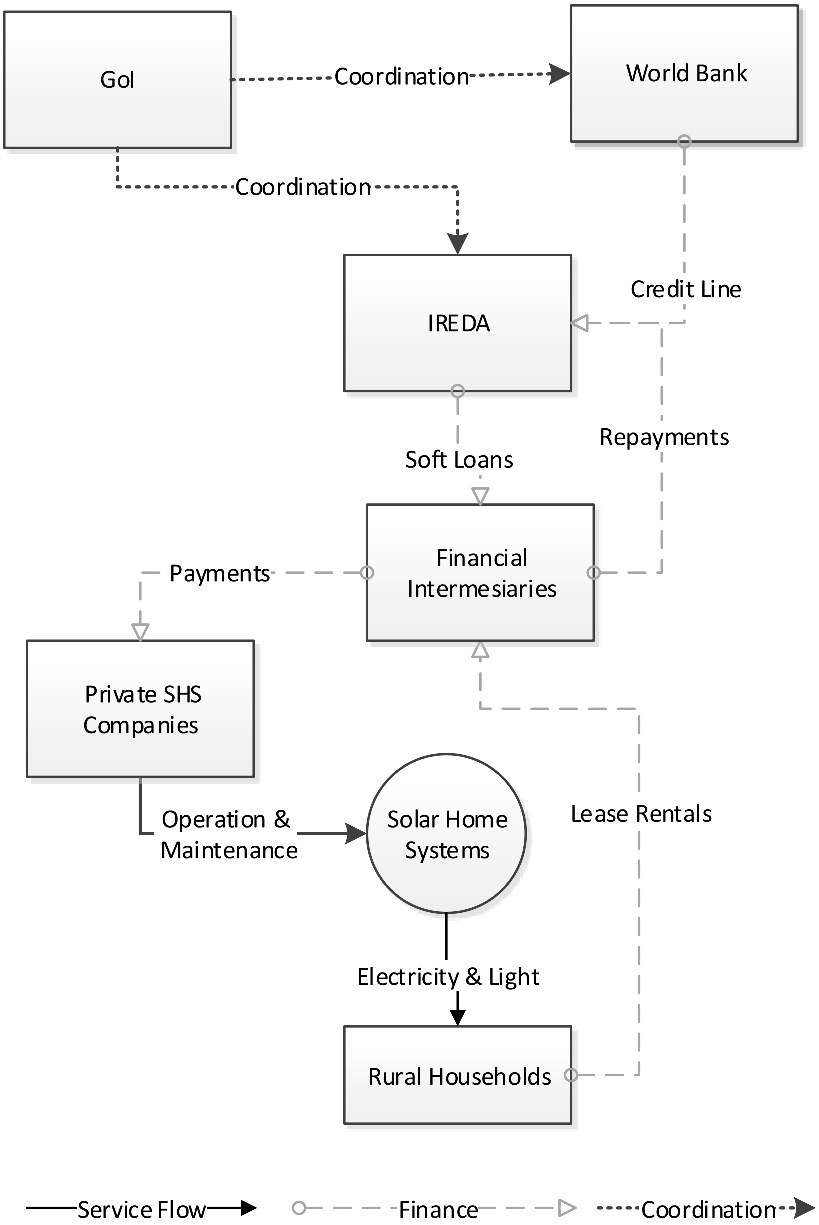


Figure 9 Service model and financing arrangements for financial-leasing intermediary schemes in South Asia

This model further evolved in the World Bank's Energy for Sustainable Development (ESD) project in Sri Lanka implemented from 1997 where the financial intermediation was retained and more emphasis was placed on the roles of the SHS companies. The model was made more market driven where the households had the choice of the SHS supplier and the choice of buying particular brands. The role of IREDA in the ESD project was played by Development Finance Corporation of Ceylon (DFCC) Bank, a development bank which channelled the World Bank funds through financial intermediaries to the households. Under the ESD project, the emphasis on quality was also extended to quality of installation in addition to the quality of equipment. A component of capital grant was also introduced in the programme which helped in buying down the cost of the SHS and was financed by a GEF grant. Another key factor which helped the rapid market development for SHS under the ESD programme was the existence of a microfinance organisation - Sarvodaya

Economic Enterprises Development Services (SEEDS), a respected MFI in Sri Lanka with a large rural presence. SEEDS played the role of an active intermediary and played a key role in providing credit to rural households to purchase SHS.

The Sri Lankan experience was replicated in the Rural Electrification and Renewable Energy Development Project in Bangladesh implemented from 2002. The role of DFCC Bank was played by a development bank – Infrastructure Development Company Ltd (IDCOL) using similar finance and service models as in the ESD project. The project in Bangladesh benefitted significantly from the micro-finance ecosystem existing in the country spearheaded by Grameen Bank. In the Bangladesh programme, the emphasis shifted to Partner Organisations (POs), such as MFIs and NGOs, which offered both technical and financial services with the SHS suppliers limiting their role to equipment supplies. Today the Bangladesh SHS programme is probably the largest SHS programme globally with almost 3.8 million SHS installed (Haque, 2014)[21] with an average annual installations of 0.78 million. The Bangladesh SHS programme has benefited from the learning and refinement of the service and finance model from the Indian and Sri Lankan programmes and was able to leverage the strong micro-finance ecosystem which exists in the country to accelerate the development of SHS markets in Bangladesh. Through concessional funding from World Bank and other donors IDCOL was able to provide loans to the MFIs at 6-9%/year interest rates against the prevailing rate of 16% and offer a loan tenure of 5-7 years against the prevailing maximum of 3 years (Haque, 2014). The current model for SHS financing in Bangladesh is shown in Figure 10.

[21] Extrapolated at 65,000 SHS installations/month.

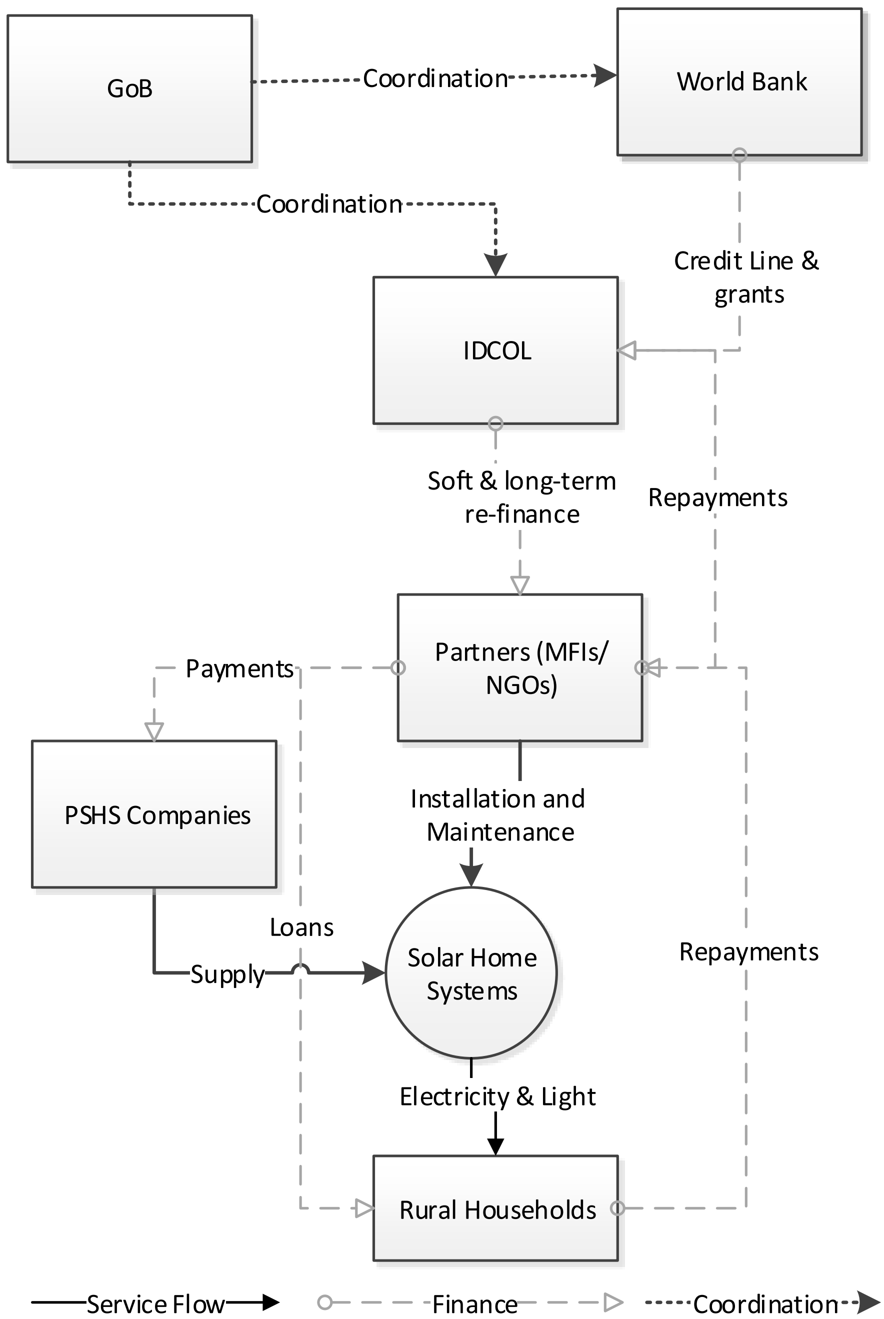


Figure 10 Service model and financing arrangements for SHS financing schemes in Bangladesh

2.4 Inference and lessons from existing SHS finance and service experience in Ghana and globally

The review of past and current models for rural electrification though SHS in Ghana as well as some of the outstanding global SHS programmes have offered some important insights and lessons which are presented below:

- There has been a fundamental change in the financing models for SHS over the last 10 years as a result of the improvements in end-use efficiency (CFL to LEDs), change in user preferences (mobile phone and portable device charging as a priority) and reduction in system prices. These changes have resulted in reducing the upfront cost of SHS to end-users, which financing schemes have tried to address.

- Consequently, financing models have also evolved from buying down the initial cost through subsidies to financing energy services over a longer period of time. Service models where the service payments have covered the cost of major components such as batteries have been sustainable in the long run.

- With reduction in upfront costs, the need for financing has shifted from end-use financing to enterprise financing. For SHS financing as a rural electrification option, existence of a rural finance ecosystem which can manage frequent transactions reliably and cost-effectively is a key pre-requisite.

- Role of governments in SHS financing has generally changed from that of the implementer to facilitator and coordinator and the implementation and service delivery role has been taken over by a variety of actors, including private sector, micro-financiers, NGOs, MNOs etc. depending on national circumstances;

- However in settings where it is not easy to crowd-in private sector and civil society actors to drive the market, governments continue to play a role in market development through policy and regulation, rather than being the implementing organisation;

- In several markets including Ghana, the penetration of mobile telephones have overtaken rural electrification rates in the past decade and SHS initiatives are piggybacking on the mobile telephone networks to offer private-sector led SHS service offerings;

- Un-electrified users and households are willing to make regular payments that are comparable to what they are currently spending on kerosene and mobile phone charging to obtain SHS on a service mode. This financing and service model is the fastest growing model and has little or no role for the government, except coordination and regulation;

- Sustainability of SHS service and financing arrangements have been observed where there is a continued benefit for or obligation on the service provider over the long run and throughout the useful life of the system.

- Scalability of SHS service and financing arrangements were also observed where the SHS market development was able to leverage an existing ecosystem of service delivery – mostly financial services and communication services.

In the Ghanaian context, based on the existing and past initiatives for financing rural electrification through SHS services the following additional inferences can be made:

- The key challenge for SHS service programmes in Ghana have been their long term sustainability. This issue is not being addressed by most if not all the current government and private sector led initiatives.

- Ghana does not have a rural and micro-finance ecosystem comparable to that of some of the leading countries that have leveraged these service channels in their SHS programmes. However, Ghana does have a strong mobile telephone penetration as well as strong MNOs, which has not been utilised effectively in its SHS programmes.

- Like elsewhere, Ghanaian SHS users have shown a preference for SHS finance and service schemes where their financial commitments are comparable to existing budgets for kerosene and mobile phone charging.

2.5 Recommendations for Ghana

Based on an analysis of existing experience with financing SHS in Ghana, key global SHS initiatives as well as the inferences articulated above, the key principles for a future approach to SHS market development in Ghana could be:

- GoG and the EC could establish a policy and regulatory framework to create a climate that encourages and incentivises long-term SHS based electrification services. Such a network should encourage service delivery more than product delivery and economic and financial efficiency.

- Utilise government and donor resources to extend the tenure and buy down the interest rates of loans to enterprises for SHS service delivery or working capital requirements that support their growth.

- Utilise all possible formal and organised financing channels in rural areas such as RCBs, CUs, MFIs for channelling credit to enterprises. Similarly, consider mobile money, CUs and *Susu* collectors can be involved in managing the financial transactions associated with the SHS service delivery;

- A range of SHS that meets the performance quality requirements as well as a range of institutions and models including, fee-for-service, rentals, PAYG models etc. should be able to deliver SHS services;

- Efforts should be made to leverage the mobile telephone networks and IT sector capabilities, which are Ghanaian strengths to improve the monitoring and administration of a financing or incentive scheme for SHS in Ghana.

Elements of a future model for SHS financing in Ghana are proposed in Section 2.6 for consideration by the GoG and the EC. The model has been proposed considering the Ghanaian experience, national circumstances as well as the experiences from Southern Africa and South Asia.

2.6 A model for financing SHS based rural electrification services in Ghana

Based on an analysis of the body of experience in Ghana on financing SHS service models and selected key SHS initiatives in Africa and Asia, it is considered that a future approach to establishing a SHS programme should consider the following principles:

- The GoG and the EC through an analysis of techno-economic factors identify areas where the rural electrification will be carried out through SHS;

- Establish a policy and regulatory framework which ensures that central and mini-grid options for electrification will be excluded from these identified areas. Include national and regional electricity distribution companies (such as ECG, NEDCo and EPC) in the ambit of this regulation.

- Establish regulations regarding initial contributions/connection fee to be paid by households for SHS services. Establish a framework for soft touch regulation of connection fee/initial payments, periodic payments for SHS services and aspects relating to ownership. It is recommended that the ownership of the systems are retained by the service providers and a system of penalties be established to prevent user abuse. The service payments should extend for the life of the system, i.e., the life of the PV module and should cover the cost of maintenance & replacements including the battery during the lifetime of the PV module.

- Establish a mechanism encouraging private companies, MNOs, civil society and co-operative enterprises in SHS service delivery. In particular encourage local Micro, Small and Medium Enterprises (MSMEs) to offer SHS delivery as franchisees, especially encouraging local youth and women owned enterprises. This could be done through fiscal incentive frameworks for MSMEs that also encourage micro-franchising. Launch the programme, actively engage partners and facilitate service delivery.

- Establish an incentive framework which allows for periodic (daily, monthly or weekly) payments of rural electrification subsidies to SHS service providers in a similar manner as electricity distributers. Consider encouraging use of mobile money transactions as well as *Susu* collectors and/or CUs to reduce transaction costs and increase transparency. Consider administering subsidy payments directly to households or franchisees using mobile money transactions to ensure transparency and openness.

- Change the focus from end-use financing to enterprise financing and establish arrangements in consultation with BoG and possibly with donor support to facilitate long term (6-7 years) finance availability for working capital finance for SHS service providers. Consider ways through donor support, lending directives and tax exemptions to provide interest subsidies for borrowings by SHS service providers. Use commercial banks, RCBs, MFIs to channel finance for MSMEs that may offer SHS services.

- The model will operate in a manner to provide SHS services by a combination of large national SHS service companies, MNOs and local MSMEs (mostly as franchisees) providing SHS services in the earmarked areas for concessions. These companies will collect a connection fee and will also receive periodic (daily, weekly or monthly) payments from the households they service. The SSPs will also receive regulated periodic payments that subsidise the SHS service. The companies that provide SHS services will benefit from low-cost or soft loans of longer tenure delivered through rural banking, micro-finance and commercial banking channels. Use of mobile money, *Susu* collectors and other channels like CUs will be used for payment collection as appropriate. Use of Information and Communication Technology (ICT) is encouraged for greater transparency and openness in the service and subsidy payments. This proposed SHS service model for Ghana is illustrated in Figure 11.

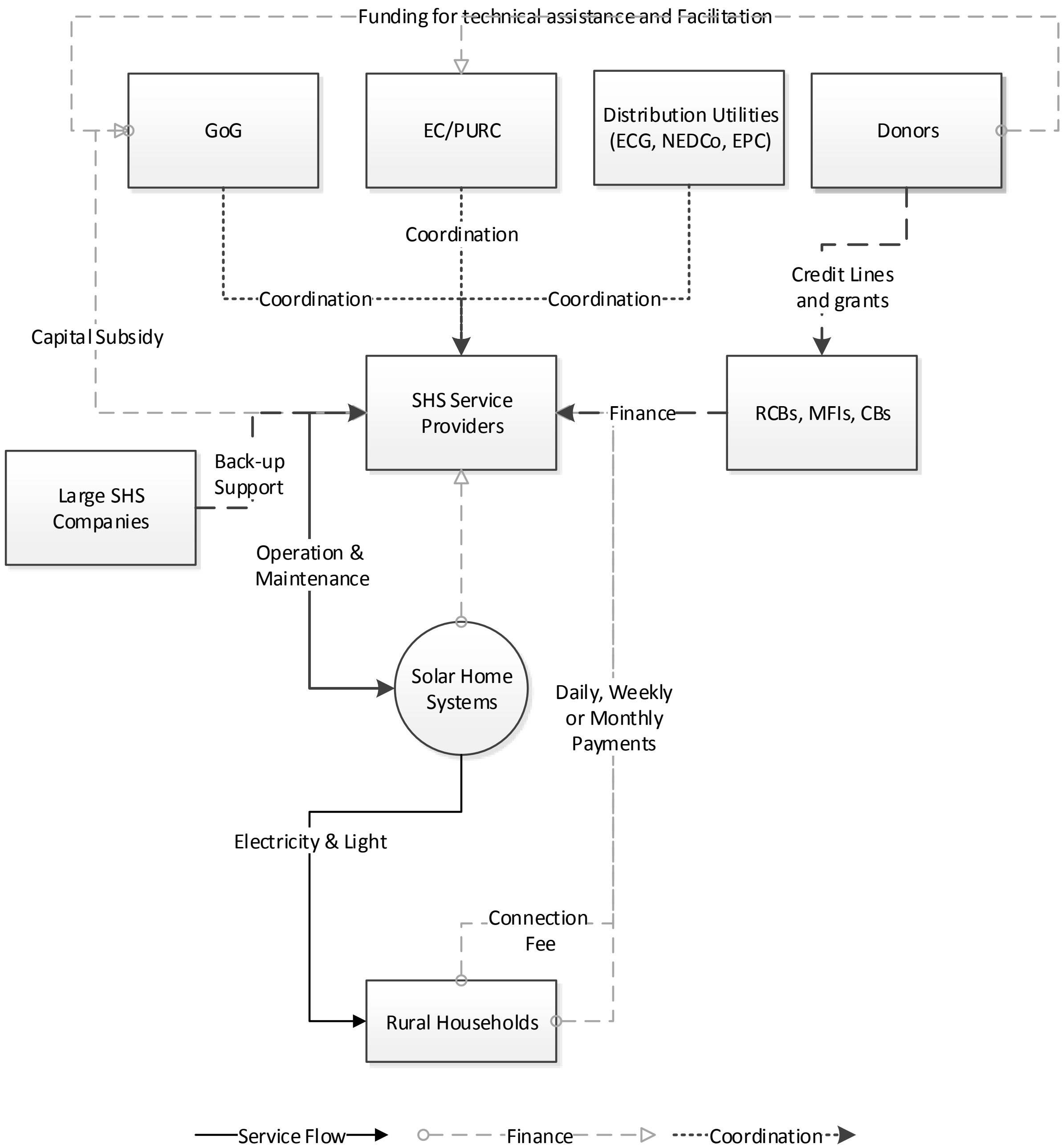


Figure 11 Proposed SHS Service Model in Ghana

3 EVALUATION OF FINANCIAL AND ECONOMIC COSTS AND BENEFITS OF MINI-GRID SYSTEMS RELEVANT TO GHANA

Emerging innovative technological solutions and business models around the globe have shown that mini-grids can play a significant role in the global energy dynamic to achieve SE4ALL's goal of universal energy access by 2030. In the un-/under-served regions where extending the grid is too expensive to justify the cost, decentralised systems using SHS and mini-grids offer cost-effective solutions. However, while SHS is adequate to serve populations that are scarcely spread and where the energy need is very basic such as that for lighting or phone charging and other very low power applications, they offer limited capability to power PUE activities vital for the socio-economic development of these regions, which is the ultimate goal of rural electrification. Mini-grids on the other hand are capable of providing a much higher level of energy services that can propel income-generating activities. They can deliver a more cost-effective alternative compared with several stand-alone systems in regions where the population density or demand (from anchor/commercial customers) is large enough to allow for economy of scale. Thus adequately financed and properly operated mini-grids play a significant role in the future of rural electrification. In addition, in case the grid is available in the future, mini-grids can be connected to the grid and act as distributed power generators thus facilitating the demand-side-management by taking care of local loads.

According to the International Energy Agency (IEA) estimates, over 40% of the new installed capacity to achieve SE4ALL's goal of universal energy access can most economically be delivered by mini-grids (SE4ALL, 2014). Existing advancements in RETs have allowed mini-grids to be cost-competitive or even cheaper on life-cycle cost basis than diesel powered mini-grids. Despite that, wide replication of RE mini-grids has been slow due to a number of barriers related to policy regulation gaps, early stage market fragmentation and unmade linkages, lack of financing, capacity, standardisation and market ecosystem, among others. Thus a clean energy mini-grids High Impact Opportunities (HIO) group within the SE4ALL framework has been formed in order to leverage the impact of existing and upcoming efforts in this field with the aim to achieve 40% of the new generation capacity using RETs (SE4ALL, 2014).

In the context of Ghana, using RETs to provide electricity to its off-grid communities has been set as one of GoG's high impact SE4ALL objectives. Majority of these communities reside in impoverished rural locations including islands and along the Volta Lake, where grid extension is uneconomical. As discussed earlier, RE mini-grids can prove vital in delivering cost-effective electrification in these communities to provide for not only basic lighting but also powering PUE activities necessary for their socio-economic development. Therefore, in order to realise Ghana's target of universal electricity access by 2020, it is important to scale-up the deployment of mini-grids in these regions. This requires an increased private sector participation in the mini-grid sector as well as service delivery mechanism that is technically sound with business model adapted to the local context.

As seen in Chapter 2, unlike the SHS sector in Ghana that has enjoyed several years of growth in the country and benefits from its past experience in the way of lessons learnt for the future, mini-grids experience in Ghana is very limited. It is also known that GoG is proposing to install mini-grids on a pilot basis. This chapter studies the best practices and lessons from international experience in the form of case studies from South-East Asia and SSA in order to propose a relevant framework for deploying mini-grids in Ghana. Factors or attributes that dictate the success, risks or failures of these service and commercial models in different socio-economic circumstances are being assessed to determine how they can be replicated and adapted to suit Ghanaian context.

3.1 Mini-grids best practices & lessons learnt

Literature shows that mini-grids are designed on one of the four business models, i.e. operated by utility, private company, community-led or a hybrid of any combination of the three. Literature and case studies have shown that the sustainability of a mini-grid is concurrently determined by a host of different interconnected attributes that influence the success or failure of the mini-grid differently, depending on type of the business model. These attributes are technical design, organisational structure, tariff design, demand side management scheme, community involvement, quality and quantity of service, support for PUE among others.

The case studies and best practices presented here analyse how one or more of these attributes affect the performance of the mini-grid given the business model and the social setting, as well as what lessons can be inferred from them. The case studies analysed in this chapter are listed in Table 1.

Table 1 List of case studies

Case study	Location	Key features/attributes studied
Off-grid Access System in South Asia	India	- Community led, NGO supported business model with multi-stakeholder engagement - Innovative cluster based techno-economic model to electrify remote villages - Support of PUE activities to enhance user paying capacity
Husk Power Systems	India	- Profit generating private sector mini-grids - Business models for scaling up mini-grid
Green Empowerment/ Tonibung/ PACOS	Malaysia	- Entirely community owned model - How community dynamics affect the success of mini-grid - Community building
West Bengal Renewable Energy Development Agency, India	India	- Hybrid model operated by either a cooperative (community) or public operated and maintained by an external private contractor - Mixed experience with community involvement
Santo Antâo Island	Cape Verde	- Hybrid model that is community owned with public-private partnership (PPP) in O&M - Innovative energy management technology
Various government and private sector mini-grids	Kenya	- Comparison of public and private sector mini-grids - Positive aspects of light-handed tariff regulation
INENSUS	Senegal	- Award winning concept of Micro Economy Model used as risk management model to create electricity market within a village - Novel tariff model and demand side management scheme
Various mini-grids	SSA	- Divided ownership of assets

In addition to the detailed case studies above, best practices and lessons are also drawn from other experiences and literature.

3.1.1 *Case studies*

3.1.1.1 Off-grid Access System in South Asia, India

Off-grid Access Systems in South Asia (OASYS South Asia) is an action based research project on off-grid electricity led by De Montfort University in partnership with University of Manchester and Edinburgh Napier University in the UK and The Energy and Resources Institute (TERI) and TERI-University in India. As a part of its research to find appropriate local solutions for sustainable rural electricity supply, the Off-grid Access Systems in South Asia (OASYS South Asia) project is implementing demonstration off-grid projects in un-electrified villages to test out various innovative techno-institutional models. One such project is a community-managed and NGO supported business model implemented by TERI to develop solar micro-grids in a remote village cluster in Odisha, India.

Situated in remote and dense forest, this cluster consists of five tribal villages and hamlets spread a few kilometres from each other as depicted in Figure 12 with a total population of 550. There was no government schemes electrifying this cluster and years of isolation meant that due to lack of developmental activities factors such as low paying capacity of the villagers, unpredictable growth demand and a scattered population kept the private sector interest at bay due to high risk involved. International research collaboration by academic and research institutes in the UK and India proposed an innovative off-grid solution for this remote, deprived community that could be technically viable, affordable, socially acceptable and manageable by the community.

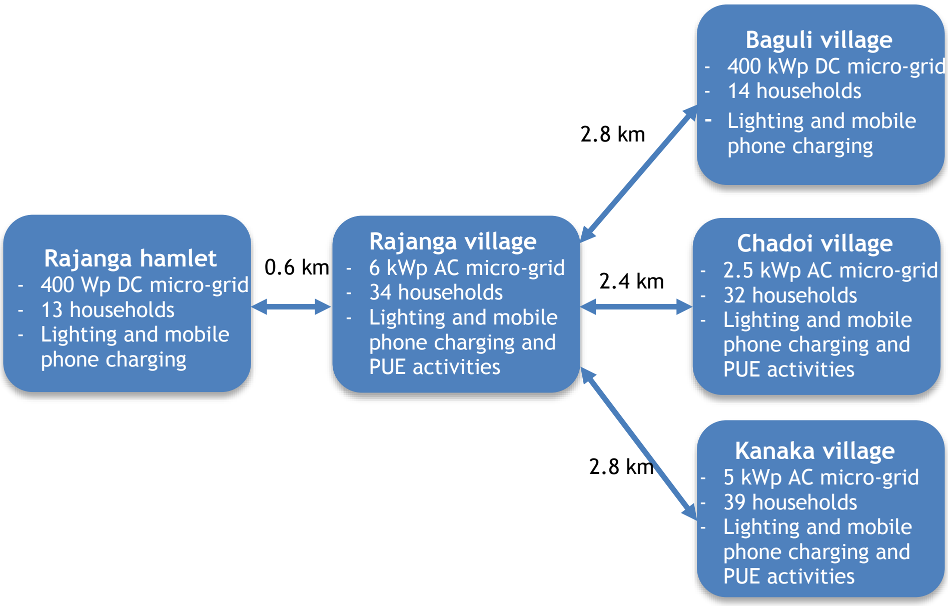


Figure 12 Geographical spread of the village cluster with respective off-grid solution

The villages are served with five separate solar plants with AC micro-grids for the three larger villages and DC micro-grids for the two hamlets. The technical design and coverage is shown in Figure 12. Regardless of the mode of supply, each household in all five villages is provided with same electrical configuration of two 3 W LEDs and a mobile charging point to maintain homogeneity while the bigger villages have additional provision for street lighting, commercial and agricultural applications and communal loads. A single institution called the Village Energy Committee (VEC) is formed to take over the collective regulatory, operational and management role of all five plants. The project is mainly financed by OASYS with partial government financial assistance and contribution in the form of land, labour and token connection cost of INR 500 from the villagers. The installation was completed in March 2014. The aim over 2-3 years is to use the electricity services to boost income-generating activities, which enhances the paying capacity of customers as well as enables them to buy more appliances, thus increasing demand. This opens the potential to attract future private sector investment on this site.

Key highlights and lessons learnt:

- While it is operationally favourable to have a large single plant, there is high cost associated with distribution line(s) running though all five villages. Having five separate plants with a single body, namely, the VEC, for operations not only optimises cost but also allows for ease of management. This cluster-based techno-economic model offers a practical solution to electrifying a small group of nearby villages and can be replicated for similar settlement patterns in Ghana.

- Solar mini-grids were used to develop livelihood generating activities based on locally available resources. For example, electric grinders for spices were made available to everyone at the village community centre as part of self-help groups and the local women were trained to use them. Similarly, mini-grids allowed for providing better irrigation facilities, water purifiers, and a face-lift to their traditional Saal leaf plate-making business. These efforts have enhanced the ability of the users to pay for electricity services thus maintaining steady revenue for daily operations as well as for future development of the plant.

- Another key achievement of this project was local capacity building. The key stakeholders involved are the VEC, the village operator, self-help groups, the community and local NGO. In remote locations, engaging external service for the plant's daily operation and maintenance activities is both expensive and difficult. Hence local institutional setup must be built to create local capabilities so that minor issues can be resolved by the community while equipped with the knowhow to reach out to the experts for more critical technical problems. In this regard, village operators selected by the VEC were trained in operation, basic trouble shooting and replacement of spare parts while VEC members were trained in basic record keeping, and banking. Local self-help groups were engaged in capacity building programmes to create awareness on energy issues and income-generating opportunities and training provided on the use and maintenance of PUE appliances. Additionally, several programmes were conducted to raise energy awareness in the community.

- Community involvement and engagement of local NGOs was a major factor in the successful implementation of the project. Land contribution and token labour for the plant was provided by the community at the beginning. The VEC was formed consisting of elected representatives from all five villages for collective decision making and coordination so as to benefit all the villages equally. The VEC is not only responsible for operation and maintenance (O&M) of the plant but also manages the community centre for supporting economic activities and for community entertainment through its village operator. Additionally, the engagement of a local NGO, IRADA, played a vital role in the development and implementation of this project. Being more acquainted with the local context, IRADA acted as an intermediary between TERI and the community. Not only did IRADA help out in the baseline studies in the early stages, it also engaged in handholding the VEC through various processes and to monitor the project since the VEC has no experience in managing energy projects.

3.1.1.2 Husk Power Systems, India

Established in 2007, Husk Power System (HPS), a private entity, builds mini-grids of capacity between 25 kWp to 100 kWp powered by biomass. A typical plant serves up to 4 villages or about 400 households within a radius of 1.5 km from the plant based on size and population[22]. HPS receives its financing through a combination of grants, loans, subsidies and equity investment from various government schemes, philanthropist ventures and other sources. It is operating its 84 plants across 300 villages under three different business models: (i) Build-Own-Operate-Manage (BOOM) model, in which HPS owns the plant and conducts the operation and maintenance activities over its lifecycle while also earning a return on capital; (ii) Build-Own-Manage (BOM) model, where the

[22] Husk Power Systems, http://www.huskpowersystems.com, accessed on June 2015.

daily operations are contracted to an independent local entrepreneur while HPS as owners keeps the profit and performs maintenance duties over the plants lifetime; and (iii) Build-Manage (BM) model, a franchise model under which a local entrepreneur uses his own investment capital to purchase a plant from HPS while HPS conducts maintenance activities only. HPS operates from Bihar, India and has expanded its franchises in some African countries (Sustainable Business Institute, 2013).

Key highlights and lessons learnt:

- Over five years of its operations, HPS has experimented with and learnt from its three different business models along with different demand management schemes and fine-tuned its operations in order to find a model that is scalable as well as profitable. It was found that scaling up with the BOOM model is difficult due to the high overhead costs involved and the difficulty in simultaneously financing and maintaining a large number of plants. On the other hand, the BM model has proven more profitable and reliable having an entrepreneur dedicated to running a single plant efficiently who directly benefits from its success. Hence, although HPS started out with BOOM models, it is moving away from this model towards the franchise BM model for future scale up of its business.

- HPS places great importance in providing a reliable service. It undergoes thorough research before construction and agreements, maintains a highly trained workforce, carries out regular audits on its expenses and addresses risks to service systematically. As a result, very little downtime is experienced. Customers are generally satisfied with the level of performance, which translates to regular payment. It was also observed that setting up a mini-grid in one village created demand for similar services in the next village since the alternative to that was the unreliable and expensive diesel/kerosene consumption.

- For payment collection, under BOOM structure, HPS sends collectors to individual households every one or two days who also check if power supply in these households are working so that customers would try not to claim discount on the grounds of poor service. This tariff collection process has proved effective for HPS. For BM plants on the other hand, the entrepreneurs set their own tariff schemes, which is usually higher than that for BOOM plants but customers are willing to pay since it is cheaper that kerosene or diesel alternatives.

- Theft has been a great concern especially under BOOM models including over-usage, use of incandescent lamps that are banned, and meter bypassing. Although HPS has experimented with various strategies to invent solutions to these problems, it has struggled with load management. Penalty for late-payment is also not enforced strictly in BOOM and BOM plants. On the hand BM plants have been much more successful in preventing theft due to on-site presence and stricter penalty enforcement, another factor that contributes to the greater success of this model over BOOM or BOM models.

  HPS has discovered that in a non-tribal village, community cohesiveness is rare where coordination among the community to collectively run a shared resource is not a natural concept. In order to involve the community more, HPS has partially mitigated this problem by directly employing the locals so that there is a motivation to perform individual task more diligently than if the responsibility was shared amongst a group.

- In order to create a self-sustained ecosystem around its plants, HPS provides income generating opportunities to the local farmers and entrepreneurs. It supports its entrepreneurs under the BM franchise model in enabling funding mechanisms to finance plants. HPS has developed incense manufacturing process that uses bio-char, a waste product from gasification plant as the raw material and employs women from the villages thus enhancing their livelihood and ability to pay. Moreover, HPS has started programmes to train the local electricians in building simple electronic products for rural microenterprises thus generating a market for such products in the village as well as supporting more livelihood enhancing activities. And finally, it builds a market for electrical products in the village by channelling products from different companies and foundations to the rural market. Not only does it benefit the companies, it also makes available more product options for the consumers to choose from[22].

3.1.1.3 Green Empowerment/Tonibung/PACOS, Malaysia

As a joint venture by three partner organisations, Green Empowerment, Tonibung and PACOS (GE/T/P), several micro-hydro powered mini-grids have been installed in villages in the Malaysian Borneo rainforest based on community ownership. Green Empowerment and Tonibung raise capital for the installation and also provide technical engineering while PACOS deals with community organisation and developing behavioural aspects. Interested communities can contact any one of the three organisations to have mini-grid installed in the village. After the initial installation, project completion and having the plant operational for a full year, GE/T/P transfers ownership to the community fully. Each village forms a committee for management and operations and develop its own customer contracts and operational rules including tariffs, collection schedule and penalties. Whereas GE/T/P secures 70-80% of the funding for the project through various donor organisations and other sources, the community as a whole covers the remaining in the form of material, labour, land or other service with contribution from each family.

Key highlights and lessons learnt:

- Since there is no external support for these community-owned projects, monetary or otherwise after the departure of the developers, GE/T/P spends significant efforts and resources into community building and organisation as community dynamics and commitment largely dictate the long term success of the project. This includes aspects such as capacity building, sensitisation to the importance of load management and system limitation and other tools necessary for coordination of operations. PACOS advocated the community against other issues such as palm oil plantation encroachment into these communities and these mini-grid projects served as a platform for collective community coordination towards a mutually beneficial venture. Each village dedicates 10,000 hours of community work into the mini-grid project including up-front labour, volunteer work for operations, etc., which has imparted familiarity with the mini-grid system and sensitivity to the practical realities faced if loads limits or proper maintenance procedures are not respected.

- As noted earlier, community coordination and cooperation is essential to the smooth operation and maintenance of the mini-grid system. Community in these villages put in voluntary work on almost a daily basis towards its operations. They are trained to handle minor repair works. Tariff collected is generally sufficient to cover the cost for O&M activities. However, in case of major issues such as severe damage to the plant due to landslide, the villagers have neither funds, nor the technical know-how to resolve the issues. On the other hand, cooperation around the usage has proved difficult in many cases. As villagers are exposed to city life, their expectation on loads increases due to greater usage of modern appliances in the households. Since the mini-grid plants were not initially designed to accommodate those kinds of loads, the excess pressure on system often causes downtime or burnout. And finally, shared responsibilities meant that individuals not assigned full task ownership have less motivation to complete their tasks resulting in sub-optimal performance such as irregular record keeping. Thus clear rules and delegation responsibilities need to be defined at the onset and a mutual understanding specified.

- These mini-grids have experienced difficulty in strict enforcement of penalties for non-payment and theft due to the close-knit nature of the community.

3.1.1.4 West Bengal Renewable Energy Development Agency, India

As the designated state agency responsible for implementing RE in the state of West Bengal in India, West Bengal Renewable Energy Development Agency (WBREDA) has installed over 20 mini-grids, mostly powered by solar PV, since 1993 serving over 2,000 customers in the state. In the early days, when WBREDA had only a few staff and hence lacked local insight and capacity to handle all aspects of the systems, the business model involved partnership with local cooperative: the idea being that a local body could instil necessary behavioural changes in the community more successfully. WBREDA facilitated the development of the cooperative along with providing financial and administrative advice. The cooperative, which is inclusive of all customers of the mini-grid, elected its own volunteer officials, set the tariff regimes, and resolutions for non-payment. Despite the integral role of cooperatives in setting up mini-grids in the early days, lack or conflict of interest caused the decline of cooperatives and instead it has been replaced by "beneficiary committee" with smaller set of responsibilities in each village. Government subsidises 100% of the capital cost while community tariff covers the O&M costs.

Key highlights and lessons learnt:

- WBREDA engages a private contractor for maintenance and operational tasks on yearly accounts, which generates frequent competition among the contractors and thus ensures better service quality. Maintenance contracts are held to high standards with on-site staff stationed to ensure reliable maintenance. In addition, presence of on-site water distillation facility reduces transport costs as well as dependence on external source for distilled water. As a result, reliable service perpetuates loyal customers.

- The arrival of mini-grids has brought about health, safety, social and economic benefits along with increased productive end uses and establishment of new business enterprises. On the flip side, increased economic activity lead to higher incomes and thus users demanded increased power and even expressed willingness to pay more for it. Customers who abided usage contracts began increasing their load before WBREDA could increase the plant size. The load limiting technology used by WBREDA such as customised current limiters and miniature circuit breakers (MCBs) proved inefficient. Thus it is important that mini-grid developers design their plants to accommodate increase generation capacity to keep up with the increasing demand and/or improve demand side management. Additionally, where tariff covers only O&M costs, the developers must ensure availability of financing for future additional generation.

- Experience with community involvement has been mixed for WBREDA. While the cooperative was crucial to the initial mini-grid development, often it hindered its operations in the later years. At the onset of the mini-grid projects, the community provided land for plant, the cooperative set out distribution paths, fulfilled key developmental roles and acted as channels for communication with the customers. However, after a few years of operation, factors such as financial interest by volunteer officials, changing leadership and political squabbles caused the decline of the cooperative institution and hence WBREDA had to adapt its business model according to these dynamics.

- Poor coordination between the Ministry of Power, India and Ministry of New and Renewable Energy (MNRE), India and their conflicting and overlapping electrification efforts resulted in central grid arriving at villages where mini-grids already existed. In those villages, rather than being integrated and complementing each other, central grid took over mini-grids completely rendering the latter obsolete. Thus it is important to have inter-agency cooperation and coordination for prudent site selection and avoiding overlapping electrification schemes and expenses. Especially were private developers are concerned, a thorough investigation on national policy towards grid extension is vital before site selection so that their mini-grid projects do not get jeopardised by the arrival of central grid.

3.1.1.5 Santo Antâo Island, Cape Verde

This solar/diesel hybrid mini-grid is located in Monte Trigo, Santo Antao Island, Cape Verde with standard electricity of 230 V, 50 Hz AC, 24 hours a day for lighting, communal facilities and PUE activities such as ice production for fish preservation. Solar generates 99% of the power with diesel used only as a back-up. Set-up in 2012, the municipality of Porto Novo owns the mini-grid fully including the distribution network. A private-public company called Aguas de Porto Novo (APN) is responsible for O&M who pays a fee to the municipality for the use of public infrastructure and charge a tariff to the users.

Key highlights and lessons learnt:

- The load management scheme called Energy Daily Allowance (EDA) was devised after interviews with the users to assess the energy requirement and willingness to pay for 24 X 7 electricity supply were conducted. EDA makes available to the users five different service levels to choose from those cap the power and energy levels as shown in Table 2.

  Table 2 EDA levels. Source: (Economic Consulting Associates, 2014)

Energy demand type	Energy Daily Allowance [Wh/day]	Power limit [kW]
Very Low	825	0,55
Low	1 100	0,55
Medium	1 650	1,10
High	2 200	1,10
Very High	3 300	1,65

  EDA is implemented through smart meters called the energy dispenser in each household which limits the power and energy according to the needs of the user. On very sunny days users are encouraged to use the surplus generation at no extra cost. This smart energy dispenser has proved effective in ensuring that the plant operates within its rated design and does not suffer from downtime or burnouts. Flat rates based on EDA has ensured smooth, cost-effective operation while matching user demand and eliminated additional metering expenses. And finally, it has reduced the risk of non-payment by the users to maintain a steady cash flow.

- The rise in economic activity and hence more power requirement resulting from greater consumption in each household, increased in need for ice production from the local fishermen and increased number of families wanting to be connected, meant that PV was expanded by an additional 12 kWp capacity. The quality of service since the inception has been excellent with diesel *genset* required only on one occasion during a festive season in the village when consumption was unusually high. Although no direct interviews with the users were carried out, these technical indicators give a rough impression of a reliable service and user satisfaction.

- Community was involved in the development since the inception, which helped imbibe a sense of responsibility within the community. Capacity building has enabled them to handle simple O&M tasks. Community consultation has also helped supply match the demand.

- Although this PPP management model has been successful so far, it has not been tested for serious failures or reinvestment. There has been a minor conflict of interest where the municipality has not paid the agreed tariff amount to the operator.

3.1.1.6 Kenya

There are over 20 Government of Kenya (GoK) mini-grids operational in Kenya with 10 more under construction (Economic Consulting Associates, 2014). They are operated on behalf of the GoK by Kenya Power (KPCL) and Kengen. Most of the mini-grids are diesel powered with a few solar/wind/diesel hybrids. Solar or wind retrofit has been proposed for the operational mini-grids under programmes such as Scaling-up Renewable Energy Programme (SREP) while 2 Kengen operated sites are to be connected to the national grid.

Kenya also has several unlicensed private mini- and micro-grids developers such as Powerhive, Powergen and Access Energy. Their systems range from 2-15 kWp serving less than 1,000 households but they have targeted to roll out over hundreds of mini-grid sites in the future. Although the existing private sector mini-grid projects are unlicensed, there is a growing interest from private sector seeking approval for licensing for their projects (Economic Consulting Associates, 2014).

Key highlights and lessons learnt:

- Pre-paid meters have helped ensure high level of tariff collection, a steady cash flow and reduced administrative costs for both the public and private operators. Also, remote operations technology is crucial for private sector to reduce further administrative costs.

- The unlicensed private sector is able to charge cost-reflective tariffs and low connection fees. Operators are automatically prevented from charging tariffs too high since they have to take user affordability and satisfaction into consideration. Thus a light-handed regulation is recommended with regards to mini-grids with tariffs being monitored rather than regulated.

- The public mini-grid makes its site selection based on distance from the grid with priority given to a site of large population. Private operators on the other hand are small in size and relatively movable even if the site is in a somewhat close proximity to the grid. Higher tariff (compared with that of utility-scale) enables faster payback period, a crucial element to their success since they receive no concession from the government.

- The heavily subsidised public sector mini-grid operators in Kenya have limited interaction with the demand side whereas the private sector has been more involved with the community and in promoting PUE activities since these breed better customer satisfaction, willingness to pay and increase affordability.

3.1.1.7 Micro Power Economy, Integrated Energy Supply Systems, Senegal

Integrated Energy Supply Systems (INENSUS) is a solar and wind technology company which focuses on innovative solutions for decentralised power supply, in mini-grids and utility grid connected systems. INESUS developed the award-winning "Micro Power Economy" business model[23] designed to create an economically and ecologically viable market for off-grid rural electrification (INENSUS GmbH, 2011). In 2010, one pilot village has been electrified in Senegal under this model under a public-private partnership and a scale-up of over 30 villages has been initiated (Sustainable Business Institute, 2013). The Micro Economy model is a risk management model with three core components:

1. *Constellation of stakeholders*: According to INENSUS, having a single operator model risks giving rise to the abuse of the operator's monopoly over a village thus provoking conflicts and vandalism. On the other end of the spectrum, a cooperative model with the involvement of the community may not possess adequate expertise to handle major technological complexities. The Micro Power Economy model proposes a compromise where all stakeholders have complementing aims and interest. An MFI lends micro-credits to the villagers for PUE and other economic activities. The villagers form a "Village Power Committee (VPC)". VPC signs a contract with a power system operator (external investor) specifying the level of service required and prices of energy. These terms of the contract are reviewed and renewed every 6 months depending on the economic situation of the village enabling the power set-up to adapt to the customers' requirements. In case of disagreements, the power system operator may be replaced. Therefore, a market for mini-grid is created instead of a monopoly by an external investor. The power system operator initially acts as the mini-grid operator until VPC takes over the operations once enough expertise has been developed. VPC buys electricity from the power system operator and sells it to the villagers. The VPC owns all the fixed assets such as power house and foundations and can avail any existing subsidies for them. The power system operator owns the movable assets such as batteries, PV modules, inverters, etc. for which subsidies should not be handed out in order to prevent market distortion. The MFI acts as the auditor of the VPC to prevent corruption and fraud. The VPC and power system operator jointly present

---

[23] SEED award 2010, https://www.seed.uno/awards/all/micro-power-economy-for-rural-electrification.html accessed on June 2015.

the proposal to the concerned authority for approval of tariff levels so that allegations of unfair/random tariff in the future can be avoided. If and when grid eventually arrives at the village, the power station may be used as a decentralised peak power station or assets moved to another village to start a new cycle.

2. *Tariff and accounting model*: Flat rate tariff is the norm in many of the existing mini-grid projects to avoid the costs for metering devices. This tariff scheme suffers from certain disadvantages. Firstly, it limits the realisation of PUE, which generally requires higher power and secondly, it provides no incentive for the customers to make efficient use of energy, which can cause accelerated battery wear, system overload and downtime/burnout. In order to overcome these, the Micro Power Economy proposes an electricity trading system with the core trading unit called an "electricity block". The electricity block consists of a power limit (in W) and energy limit (in kWh), which can be used in a given period of time (say a week). A user can order a number of electricity blocks according to expected demand. In case of short-term need that exceeds the ordered demand, the user can demand more power at an extra cost, which reflects the additional battery wear/fuel consumption. After the 6 months when the contract between the power system operator and VPC is up for renewal, the users can adapt their order according to current demand and financial situation. The VPC sums up the electricity blocks and places a bulk order to the power system operator who in turn adapts power and capacity of the plant accordingly, thus supplying electricity at a relatively low price. A bulk order for electricity block can be used to create an electricity block market within the village. In case some users who are unable to make payments may choose to sell some of their pre-paid electricity blocks to the market while others who may have ordered extra power in the beginning of the contract may buy the available electricity blocks from the market for prices dictated by supply and demand. This enables the latter to avoid having to buy extra power at extra cost as described earlier.

3. *Load management and accounting unit*: Using the traditional load limiters for demand side management limits the available power to users for higher power applications such as PUE. The load management and accounting unit (LAU) overcomes this issue through an active load management approach using grid frequency measurements that allows single user to run PUE devices while also limiting the total power used based on the capacity of the plant. LAUs are installed at each household, which communicates directly with the power station. Priority users are pre-defined based on certain parameterisation. When demand exceeds the available capacity of the plant, the grid frequency drops. Below a certain threshold, the lowest priority users are disconnected by the LAU first by random choice while high priority users such as a hospital remains connected. On the other hand, when there is surplus generation, grid frequency rises. Deferrable loads such as water pumps are then automatically turned on by the LAU. LAUs are combined with prepaid meters in a single housing placed in the public to prevent theft. Customers use a chip card to manage their account, which includes topping-up their LAU accounts, checking current account status, trading electricity blocks, etc. Upfront payment ensures timely cash flow to the power system operator and thus leads to planning security for mini-grid.

Although the pilot projects are installed only in Senegal so far, INENSUS sees a huge potential to scale up this model in Africa. It offers to implement the Micro Power Economy approach adapted to the local political, socio-economic and infrastructural framework on behalf of interested customers including planning, technical design, installation and commissioning of the projects.

3.1.1.8 Sub-Saharan Africa

A particularly successful business model for solar powered mini-grids that has been adapted widely in SSA region is one where the assets of the mini-grid system are owned by separate entities. This is similar in concept to the ownership model of Micro Power Economy discussed above where the fixed assets of the mini-grid such as the power house, transmission and distribution lines, poles, guys, anchors, metering equipment, etc. are owned by the community or the government whereas the mobile assets associated with the generation technology such as PV panels, batteries, inverters, charge controllers, etc. are owned by an external operator. There are several major advantages to this model:

- Since the expenditure on fixed assets is borne by the government, the community or both, and not by the operator, the cost of subsidy required to bring down the tariff to affordable levels for the users reduces.

- As the operator now only has to invest in the generation technology rather than setting up the entire mini-grid infrastructure, the operator's capital expenditure (CAPEX) is reduced significantly, which encourages greater private sector participation due to lower risk on investment.

- In case of disagreements or unsatisfactory service, the operator can be replaced. This incentivises better performance from the operator. Even if the operator is replaced, goes bankrupt or decides to move, the infrastructure still remains with the community and the new operator needs to assess its investment only on the CAPEX of the generation technology and its associated operating expenditure (OPEX).

3.1.2 Best practices and lessons learnt from literature and other experiences

Planning

- In sizing the mini-grid system, demand for electricity needs to be accurately assessed to be economically sustainable. Oversizing the system increases the cost the users have to pay, which affects the affordability of the electricity service. On the other hand, when the system is under-sized, supply does not match demand, leading to user dissatisfaction and thus reduced motivation to pay. Furthermore, the demand is likely to grow over its lifetime. Hence the system should be designed to be incrementally expandable as well as demand side management must be effectively implemented (United Nations Foundation, 2014).

- From the perspective of private sector and other for-profit ventures, careful market selection is especially important to earn return on investment. Developers may select their market based around anchor customers to ensure a reliable flow of revenue or build a reliable customer base by investing in PUE loads to enhance user income.

- Aside from technological considerations, the delivery model should be adapted to the local social and economic conditions (Alliance for Rural Electrification, 2011) as well as political context. Initial assessment should be carried out to assess socio-economic factors such as ability to pay, user interest, and how they affect the selection of management entity (ESMAP, 2000).

Technology choices

- Appropriate design choice between AC and DC mini-grids is influenced by several aspects including commercial viability, technical risks, standards/benchmarking and global experience (TERI SRC, 2015). While DC mini-grids can provide for basic household needs (lighting, phone charging and fans) at a lower cost than AC mini-grids, they are limited in their capacity to service high power appliances. DC is safer to use on devices, which is why DC systems are widely used in IT based organisations with a surge in appliances such as television and power electronic controlled motors coming with DC internal circuits. However, in terms of health safety, there is no difference between AC and DC. The AC market ecosystem is far more developed than that of DC with many appliances running only on AC. Thus the cost of DC appliances currently is 20%-30% higher than that of AC. And finally, there is very limited experience with DC mini-grids and hence a dearth of proven scalable DC mini-grid models.

- Technological devices such as smart-meters, automated payment, collection technologies or other load management devices can help in remote monitoring and operations reducing costs on administrative and human resource but increase the capital cost. The developer must weigh in the balance between expenses of added technology and larger human resource. If the developers opt out of automated solution, they must also spend time and effort in identifying, training and motivating people to carry out necessary operational activities (United Nations Foundation, 2014).

Tariffs

- Setting appropriate tariff and subsidies is one of the single biggest factors in determining the sustainability of mini-grids (Alliance for Rural Electrification, 2011). The tariff structure for different business models can have significant differences. In community operated models the tariff is designed to break-even on cost coverage. Profit oriented business models design higher tariffs to generate sufficient return on investment. When tariff is set too high it becomes unaffordable to the users whereas when it is set too low, sufficient revenue for operation of the plant is not generated. Hence tariff should be a balance between developer's motivation and customers' expectations.

- Many case studies have shown that strict enforcement of penalties for non-payment increases the likelihood of payment (United Nations Foundation, 2014). It is also preferable to hire an external salaried collector than choosing one from within the community since it is often seen that in the latter case, the collectors struggle with confronting their friends and relatives for non-payment or enforcing penalty. The developers may also choose to make use of technology for automated payment.

Box 3.1: Mera Gaon Power, India

Mera Gaon Power (MGP) builds, owns, operates and manages solar DC micro-grids in impoverished off-grid communities in Uttar Pradesh, India to provide basic lighting and mobile charging facilities to its customers to replace kerosene lamps. According to MGP, they have covered about 80-90 villages so far. A key factor in success of their scale-up has been the efficiency in their tariff collection mechanism.

MGP has priced their tariff to cost less than half of the users' monthly expenditure on kerosene. Tariff was initially fixed at INR 100 (USD 1.6) per month. As the daily income of the villagers is very low often earning less USD 1 per day, paying INR 100 a month in bulk becomes difficult for the user. Hence the tariff was revised to INR 25 per week, which made it easier for the users to pay. The weekly collection of revenue is carried out through a Joint Liability Group (JLG). A JLG is a group of customers who avail electricity services and pay for it collectively. The JLG model has helped MGP reduce their operational expenses since their collectors do not have to make door-to-door collections. This model also minimised the risk of non-payment. If one user in the group is unable to make a payment then the JLG pays on that user's behalf and ensures that timely repayments are made. JLG has also helped optimise the route for payment collection thus reducing fuel cost in transportation.

Grants and subsidies

- Grants and subsidies play a significant role in determining tariff, affordability and scalability of mini-grids. They should be high enough to make mini-grids affordable to users as well as attract private-sector investment and at the same time be as low as possible so that mini-grids can be scaled up beyond a pilot project (European Union Energy Initiative Partnership Dialogue Facility, 2014).

Other factors

- Operational diligence: Operational discipline such as maintaining meticulous record keeping (of payments and expenditure), operator logs, reliable customer support and quickly addressing problems, frequent site visits and theft investigation, maintaining proper operational schedule, etc. contribute in smooth operation of the plant preventing downtime and breeds customer satisfaction thus increasing likelihood to pay.

- Maintenance: Regular maintenance of the system such as cleaning of solar panels, necessary minor repairs and replacement of defective parts, topping of batteries with distilled water, trimming branches, etc. is necessary to prevent major corrective and expensive repairs in future. Apart from physical elements, maintenance performance also depends on the institutional element, i.e. the entity responsible for carrying out the maintenance. Robust monitoring and regular reporting from the maintenance contractor should be performed. There should be no ambiguity over responsibilities for routine maintenance. Proper communication channels should be facilitated among the beneficiaries, developers and maintenance providers so that there is a transparent procedure for placing maintenance or service requests.

- Security: Security is another vital factor in site selection and security concerns varies across different regions. These can include presence of rebel factions, tribal/group rivalry, highway banditry, theft and vandalism. These may affect the daily O&M activities and pose danger to the employees of the plant.

3.2 Recommendations for Ghana

3.2.1 Overview of Ghanaian present conditions

The GoG is strongly committed in pursuing RE based solutions to electrify its unserved or underserved lakeside/island communities. These regions have abundant solar energy resource as well as potential wind resource in some of the islands to support hybrid mini-grids. The demand for mini-grids in Ghana has been estimated at about 350,000 people in 400 communities, mainly in islands and lakeside (Aide Memoire. Scaling-up Renewable Energy Program in Ghana, 2015).

Ghana's experience with mini-grids has thus far been almost non-existent. As a result, regulatory framework for mini-grids is being developed by the Ministry of Power (MoP) along with the EC and the Public Utilities Regulatory Commission (PURC) to address the challenges in mini-grids to scale up and accelerate rural electrification. The MoP, through GEDAP under World Bank financing has commissioned the development of 7 mini-grid pilots in selected lakeside and island communities on the Volta Lake. These pilot projects will help the GoG learn which business models best suit Ghanaian conditions, what would be the actual cost of O&M, how much are the users willing to pay, etc.

In the meantime, best practices and lessons from mini-grid experience in other countries can serve as a useful guide to develop a framework for business models that could be adapted and replicated in Ghana. Based on the analysis of the existing experience and insights in Section 3.1 the following guidelines are presented for Ghana.

3.2.2 AC mini-grids vs DC mini-grids

Ghana is not focussing merely on electrifying its deprived communities but also on promoting the productive use of electricity services in the design and implementation of its rural energy projects. As discussed in Section 3.1.2, DC mini-grids are not adequate to power productive loads. Hence, it is recommended that Ghana opt for AC mini-grids over DC mini-grids.

3.2.3 Strategic planning

Community consultation at early stage should be done to gauge their interest, affordability and make demand assessment and projection, community dynamics, etc. Awareness on the benefits of mini-grids must be created within the community as they may be reluctant to accept decentralised solutions preferring "real" electricity through grid connection.

Time and effort must be spent on capacity building, training and creating a proper institutional set-up for running the plant, especially in mini-grids models with greater degree of community involvement. Market development (more in Sections 3.2.10 and 3.2.11) through creation of income generating activities will contribute to long-term sustainability of the plant.

3.2.4 Tariff

Although currently the GoG is implementing its rural electrification programmes on a unified tariff system, for the growth of mini-grids in the future, a recommendation to encourage cost-reflective tariffs is made, which would ensure market sustainability and thus attract wider private sector participation. One approach to achieve this would be light-handed tariff regulation. Tariff should be monitored rather than regulated. Developers may choose to hire tariff collectors or make use of automated payment through technological solutions to reduce transaction costs. As suggested in the case of SHS, the use of mobile money transactions, S*usu* collectors and/or CUs should be also considered. In case of the hired tariff collectors, the collector should preferably be external to the community and salaried. Innovative tariff collection mechanism such as the JLG method of MGP or tariff model of Micro Power Economy can be considered. Penalties should be strictly enforced to discourage non-payment from the users.

3.2.5 Subsidies

Subsidies should be a balance between making mini-grids affordable for user and attracting private sector investment, and scaling up mini-grids beyond a few pilot projects. Since the GoG is committed towards a uniform tariff system, the subsidy could be given on CAPEX to bring down the tariff at uniform level.

3.2.6 Public policy, legal issues and contracts

Policies and regulatory framework should clearly demarcate SHS, mini-grids and central grid communities to avoid overlapping electrification schemes and expenses with clear inter-agency coordination. Firm legal contracts should be put in place among all the stakeholders, i.e., developers and customers, developers and suppliers, and among the developers, operators, maintenance contractor, etc. in hybrid models involving multi-entity partnership. Roles and responsibilities for all O&M tasks must be clearly defined.

3.2.7 Demand side management

Load management is necessary to ensure that plant operates at its rated capacity to avoid system burnouts and downtime. Use of energy efficient appliances should be promoted. Customers should be sensitised about the importance of load management and the practical reality faced if load limits are not respected. Strict penalties should be enforced for offences such as overuse or theft.

Replication of demand side management techniques such as that employed in Cape Verde, i.e. EDA and Micro Power Economy can be considered. Energy efficient appliances such as LEDs should be made available locally.

3.2.8 Maintenance

Installing on-site water distillation chambers for batteries can help cut down transportation cost and reduce dependence on external agencies as seen in the case of WBREDA. This could be especially significant in remote communities in Ghana with bad transportation links to the nearby towns.

Maintenance contracts should be handed out on a competitive basis and on a periodic basis ranging from at least 6 months to not more than 2 years so that the contractors are incentivised to carry out their tasks properly. Diligent monitoring and record keeping must be performed for both the physical (expenditure on repairs, spare parts, operator logs, etc.) and institutional (employee performance, etc.) elements of maintenance.

3.2.9 Community involvement

Care must be taken when determining the degree of community involvement in the project as community dynamics vary widely across different regions and experience has shown mixed results. In most case studies, the effect of active community involvement at the beginning of the mini-grid development has largely been positive[24]. However, over the long run in the lifetime of the mini-grid, which can be 20-25 years, community dynamics is likely to change due to factors such as volunteer members seeking personal gains over collective benefit, changing leadership and political squabbles, or lack of enough motivation owing to shared/ambiguous responsibilities etc. that can severely affect the performance of the mini-grid. One of the partial solutions could be to hire salaried employees within the community to carry out certain tasks instead of engaging volunteered contribution.

Community are often ill-equipped to take up complex technological repair works in terms of finance and capacity. Provisions should be made to handle such situations when opting for community owned business models.

3.2.10 Productive uses of electricity

As it has been seen in numerous cases studies, presence of income-generating activities is necessary to ensure a reliable and steady source of revenue to sustain mini-grid in the long run. Hence, regardless of whether the developer is a utility, a private investor or the community, efforts should be spent on developing PUE activities in the community. When making the initial demand assessment, consider taking the suppressed PUE demand into account, i.e., the PUE loads that could be developed if electricity was available. For instance, on the Consultant's field visit to Pediatorkope in December 2014 as a part of the inception mission, it was observed that there is potential to develop a palm oil harvesting facility in the island if electricity was available. If such activity is to be developed along with the development of mini-grids then demand assessment/load analysis should also include such supressed PUE demand.

3.2.11 Development of market ecosystem

In un-electrified island/lakeside communities, the market for energy is usually underdeveloped and mostly dominated by firewood, charcoal, kerosene, dry cell batteries, etc. if present. Taking lessons from the HPS approach, efforts should also be made to create a sustainable ecosystem around a mini-grid plant, which includes not only developing PUE activities but also facilitating market development for electrical appliances and supply infrastructure in the community by using mini-grid plant as the platform to channel products from different companies to the users. This would be a mutually beneficial venture for all the stakeholders: the companies get a larger customer base, the users have more products available to them, and the developer has a thriving market for its electricity service.

3.2.12 Local champions

Local bodies with responsibilities such as the church or NGOs could play an important role in rallying the villagers and handholding the community in promoting PUE activities, awareness creation on energy issues, and other developmental activities as seen in the OASYS case study. Furthermore, cooperation and collaboration between multiple NGOs, each with its own strengths and portfolio, can positively contribute towards a successful venture (as seen in the case of GE/T/P).

3.2.13 Potential for replication

- The cluster based approach of OASYS project to electrify a group of nearby villages can deliver a cost-effective electrification solution with ease of management. Having a single management body such as the VEC can promote cross-learning between the villages. This model has demonstrated a sustainable community managed and operated project with

[24] As seen in case of WBREDA, OASYS, GE/T/P and Kenya

handholding support by a local champion and technical support by the implementing agency.

- HPS's franchise model of BM has seen good potential for scale-up due to its profitability and thus attractive to the private sector. Rather than having multiple plants to operate from a central location, which can be a cumbersome process, the build and maintain structure transfers major responsibilities to the local entrepreneur who, due to on-site presence, can handle operations of the plant more effectively and is also incentivized to do so since the success of the plant directly results in direct benefit for the entrepreneur.

- INENSUS' Micro Power Economy is a well-rounded business model that mitigates risks associated with O&M and for all stakeholders involved, and applies efficient tariff model and effective load management scheme while also creating an energy market within the village community. INENSUS provides solution customised to the local regulatory, social and political setting by adapting its Micro Power Economy approach to fit the local context to interested customers. This model is currently implemented at a pilot site in Senegal and initiated scale-up in around 30 more villages. INENSUS is looking to scale up the implementation of this model in Africa. Ghana can look to engage INENSUS in a PPP in applying this business model in some of its off-grid communities. Alternatively, Ghana can also adopt the modified form of Micro Power Economy's ownership model independently of INENSUS that has seen great success in various SSA regions, where the fixed assets of the mini-grid are owned by the government or community while the movable assets are owned by an external operator.

4 EVALUATION OF THE FINANCIAL AND ECONOMIC COMBINATION OF SHS AND MINI-GRID SYSTEMS

Ghana's commitment to SE4ALL presents significant investment opportunities in its SE4ALL high priority areas; access to electricity for off-grid communities using RES and access to modern energy for productive uses are among Ghana's high priority SE4ALL objectives. These two high priority areas are interlinked since the former can provide access to modern energy for the later. It is important to identify opportunities in these areas that are financially and economically viable.

Chapter 2 and Chapter 3 have analysed past experiences in SHS and mini-grids. These chapters have also recommended service/business models applicable for SHS and mini-grid systems most suited to Ghanaian circumstances. The GoG has already demarcated the communities who will be served by off-grid RES. The next challenge is to decide under what circumstances, standalone systems, i.e. SHS and/or mini-utility make for a better choice to serve a community than a distributed system, i.e. mini-grid and vice-versa. What is the technical/financial crossover point between having standalone SHS/mini-utility system and a mini-grid? What are the opportunities where these systems can be used in combination to best suit the needs of a community?

The decision making process in addressing these questions are multi-dimensional in nature. Firstly, the technical, financial and socio-economic features vary from region to region and are very site specific as well. Hence, it is important to evaluate each case individually to fit the local context. The suitability of one RES system over others will depend on various factors such as load profiles, energy requirements, terrain characteristics, size of the community, spread of the end users, resource availability, capital costs, O&M costs, ability and willingness of the end user to pay, other social factors, etc. This creates a need for a decision making mechanism that evaluates these factors systematically in an ordered process to arrive at a decision to select the most suitable off-grid RES.

Secondly, such a decision-making mechanism must also address the interests of several stakeholders.

- From the government's point of view, the GoG is supporting SHS as well as mini-grid programmes. It would need to evaluate the suitability of various options for providing its support in an equitable manner and as a social good.
- Private sector developers are interested in deciding whether the investment in potential off-grid RES project will yield any profitable return on their investment and if so, by when and by how much.
- From the users' perspective, they have to decide whether they are interested in such a project and if they can afford to pay for the electricity services provided.

Thus to address the above challenges, a decision tool is proposed in this chapter, which presents a logical and ordered process to assess the current situation of the community, evaluate the alternatives and arrive at an optimal off-grid solution, while capturing the ground realities. This decision tool is aligned with the needs of the government, the project developers and the users, and acts as a guiding principle to assist them in decision making. It is presented in the form of a flow chart, supported by matrices with qualitative and quantitative parameters.

4.1 Overview of the decision tool

As discussed above, selecting a suitable off-grid RES for electrifying a particular community is a complex process involving a host of technical, financial, socio-economic and organisational parameters. Additionally, it requires a hierarchy of decision making process involving several stakeholders while ensuring that the processes are inclusive, as they support both top-down and bottom-up approaches. The decision tool proposed here aims to simplify this process by addressing the challenge at three different levels: macro level, meso level and micro level as explained in the following subsections. Not only does the decision tool break down a large issue into three smaller ones to manage, but also aligns with the roles and responsibilities of different stakeholders at different level of decision making hierarchy and builds-in a flexibility to move across the levels as required.

4.1.1 Macro level

At the macro level, the decision tool aids the policy makers who are at the first level of the decision making hierarchy in deciding whether to provide electrification to a community through grid extension or serve the community using off-grid system. The first decision trigger at this level is the distance of the community to the national grid, the rationale being that above a certain distance, it becomes much more expensive to extend national grid lines than to set up decentralised system(s). Information on distance of a community from the central grid tap is readily available and thus serves as a quick and practical indicator to decide between grid and off-grid system. In Ghana, it has been decided that communities with population above 500 and having road connectivity will get grid connectivity eventually[25] irrespective of their distance from the grid. The decision tool is designed to be robust so that it can adapt to local contexts and dynamic situations.

4.1.2 Meso level

After a decision has been taken to opt for off-grid system, further evaluation needs to be carried out to determine the most appropriate RES system solution. A complete solution depends not only on the technical and financial parameters, which are quantitative in nature, but also on qualitative socio-economic parameters. At meso level, the quantitative aspects of the RES systems design are more prevalent. The project developers, which include utilities, independent power producers (IPP) and other private sector players, are the responsible bodies for evaluating these aspects through actual site visits and interaction with users. In the context of Ghana, the GoG is planning on being strongly involved in the development of decentralised RES systems for electrification. Thus at meso level, the decision tool supports the GoG as well as project developers.

The load type is used as the first trigger to decide the kind of RES system most appropriate for a potential site. Communities with only household loads can be served by SHS. If it has both household and communal load(s) such as a health centre or a school but no productive loads, then the households can be served by SHS while the communal facility by mini-utility. When PUE is involved, it justifies a case for either mini-grid or a hybrid system. Decision between mini-grid and hybrid system is made on the basis of how densely the end users are spread, the topography and the geographic area.

Following that, a further detailed techno-economic analysis for each RES type is carried out. This consists of resource assessment to decide the best generation technology option among solar, wind or their hybrid. Then the expected energy demands are provided in order to estimate the potential plant size and estimate of the potential installation costs. These are used to derive the levelised cost of energy (LCOE) that can be then used to calculate an indicative tariff and determine payment options. In case of SHS, appropriate service models and financing modalities are evaluated and based on recommendations made in Chapter 2, service model and payment options for the users is proposed.

4.1.3 Micro level

As discussed, the qualitative aspects play an important role in arriving at a complete off-grid RES system solution for a community. From the community point of view this includes the interest of the user in participating in such a development, prosperity level, ability to pay, willingness to pay, quality of services expected (including duration and capacity), payment options, security situation, community cohesion, and other social factors. On the other hand, the project developers require an understanding of regulatory conduciveness, government presence and support, access to technical knowhow, supply infrastructure, etc. These characteristics form a crucial basis to develop a business model that is tailored to the needs of the community and the project developer. Thus micro level qualitative aspects are more prevalent. At this level, the decision tool supports both users and project developers including the GoG in a supervising role in carrying out the socio-economic study to aid in the decision making.

---

[25] As per the information received during the Consultant's mission to Ghana in February 2015

There is a great degree of interplay between the meso and micro levels. For an accurate demand assessment at the meso level, it is necessary to survey the user's expected quality of services, which affects the system sizing. The indicative tariff and payment options proposed at the meso level will be necessary to assess the user's willingness to pay and the preferred payment mode. In addition, the payment mechanism affects the cash inflow, which then affects the O&M costs. And finally, to assess the presence of PUE and thus the decision between mini-grid/hybrid and SHS/mini-utility, it is also crucial to assess the supressed PUE demand (income-generating activities that can be created if necessary electricity demand is present). This demand is assessed making a site specific qualitative evaluation such as the presence of NGOs or churches that can help develop these activities. Thus this decision tool is a balance between top-down and bottom-up approach to yield an optimum RES solution that includes both technical design and commercial model.

Table 3 presents a brief overview of this multi-level decision making process. It identifies at each stage, what needs to be done, how is to be performed, whom is the tool designed for and what are the expected outcome(s) respectively.

Table 3 The decision matrix

Level	What	How	For whom	Outcomes
Macro	• Grid tap proximity • Population • Road connectivity	Using statistical and secondary information available such as population, road connectivity, etc.	GoG	• Demarcate clearly the areas chosen for grid extension vs off-grid solutions
Meso	Technical parameters • Topography • Population density • Site layout and extension • Resources (solar, wind) • Load profile • Demand assessment Financial parameters • CAPEX • OPEX • Subsidies, grants, etc.	Site visits to assess topography, site layout, etc.	GoG along with the project developers including utilities, IPPs and other private sector player	• Decision: SHS, mini-utility, mini-grid or hybrid option including system design • LCOE • Estimated indicative tariff from LCOE • IRR • Cashflow
Micro	• Willingness to pay • Ability to pay • Expected quality of services • Security • Community cohesion • Regulatory aspects • Presence of church, NGOs, etc. • Supply infrastructure	Interacting with the locals, assessment of the regulations and supply infrastructure, etc.	GoG along with the project developers and users.	• Implementation model including ownership and operator model, payment option (prepaid or post-paid), etc., tariff model • Business model tailored to the community's needs

4.2 Key concepts

This subsection explains the key concepts and the line of reasoning used in developing a decision mechanism for choosing among several off-grid RES. It first presents the definitions for these systems used in this report, and then describes different kinds of loads and finally, the most appropriate RES for these loads.

4.2.1 Definitions of various off-grid RES systems

Solar home systems

Description: Isolated power systems complete with solar module(s), battery storage, charge controller and appliances, supplying one individual establishment (e.g. household) without distribution grid. In this report, solar lanterns are also included under the category of SHS. Solar lanterns are portable lighting systems comprising of a lamp, a PV panel and a battery that charges during the day and provides lighting during the evening/night. However, the solar market is constantly developing with innovative concepts all over the world. For instance, a multi-national SHS company sells a solar product that is basically a solar lantern with a USB port for phone charging. On the other hand, there are solar companies in Ghana that provide SHS with one fixed light and one portable lamp that is similar in concept to a solar lantern. Thus, SHS and solar lantern markets are evolving in a manner that the boundary between their definitions is not clear-cut anymore. Hence, solar lanterns have been paired under SHS. Typical size for this category of systems is taken to be up to 1 kW for this report.

Illustration:

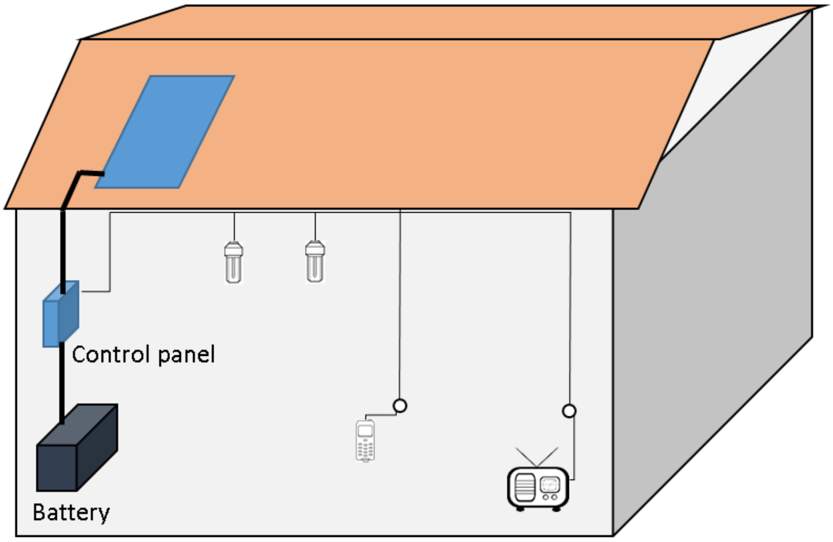


Figure 13 An example of a solar home system

Mini-utilities

Description: Mini-utilities are also isolated systems designed to provide a multitude of services to a large community of users. Depending on the availability of resource, mini-utilities can be designed to use a combination of solar, wind, biomass, etc. to generate electricity. Mini-utilities are typically installed on rooftop or on ground within the premise of communal facilities such as church, school and clinic. They can also be used as a mini-enterprise to provide services for multiple applications such as to charge battery and run small machines, which can be used by the community members and where users would typically pay for services on an hourly basis. Technically, mini-utilities are larger in capacity than SHS for communal use while functioning without power distribution network unlike mini-grids. This report considers a typical size of mini-utilities to be in the range of 1 kW to 100 kW.

Illustration:

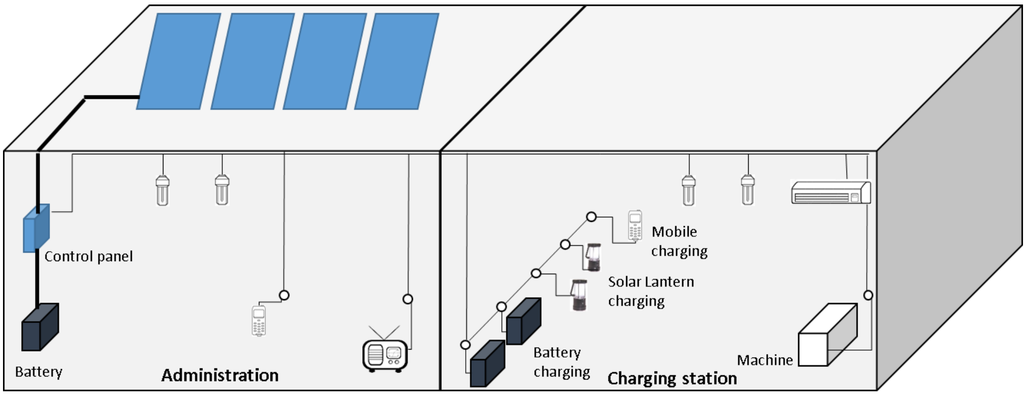


Figure 14 An example of a mini-utility

Mini-grids

Description: Mini-grids are single or various power systems (installed capacity typically of 10 kW to 10 MW) feeding electricity into a small distribution grid designed to generate electricity centrally and providing the same for various applications to establishments spread within a designated geographical area. Mini-grids essentially have centralised electricity generating capacity mainly consisting of renewable energy generator, a battery bank to store the electricity, power conditioning unit (PCU) consisting of junction boxes, charge controllers, inverters, distribution boards and necessary wiring/cabling, etc., all located within an appropriately constructed building, and a power distribution network (PDN) to carry power to individual houses and other entities. Technically, mini-grids can be distinguished from mini-utilities by the presence of low to medium voltage distribution line(s) for transmitting power directly to the end user.

Illustration:

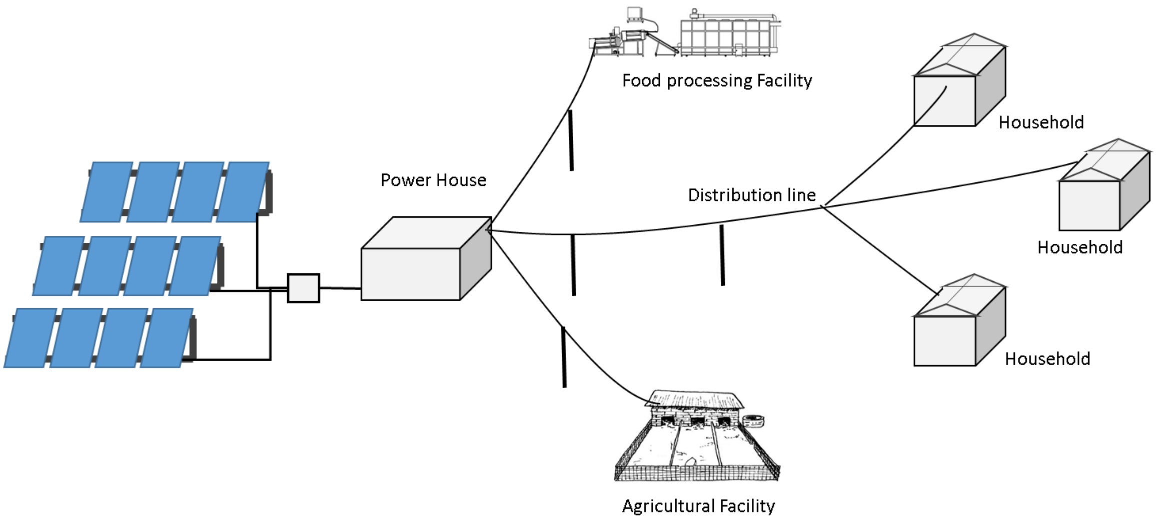


Figure 15 An example of a mini-grid composed of various households and PUE facilities

Hybrid systems

Description: Hybrid systems can be any combination of SHS, mini-utilities and mini-grids providing electricity within a community. Hybrids can prove to be economically better option over other individual solutions in certain cases. For instance, when a community can be electrified by a mini-grid but there are scattered households within the community, albeit at a significant distance from the load centre, then the former can be served by SHS while latter by mini-grid.

Illustration:

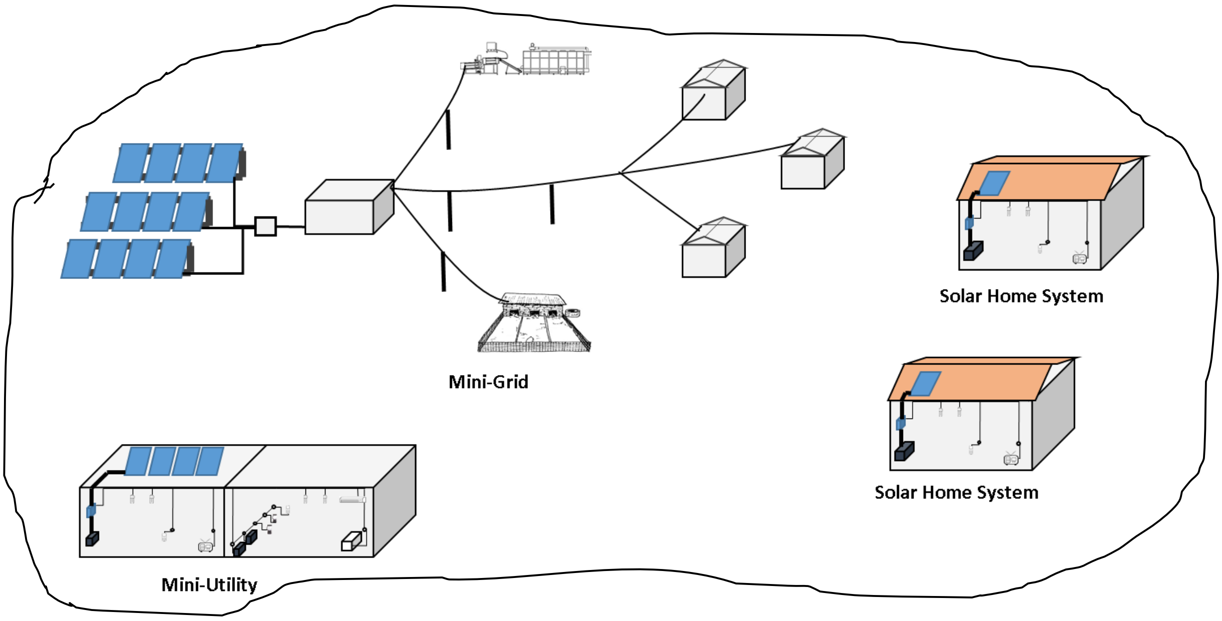


Figure 16 An example of a hybrid system composed of mini-grid for clustered load and SHS and mini-utility for scattered establishments within a rural community

4.2.2 Loads

As per the Global Tracking Framework (GTF), a multi-tier framework has been proposed to measure access to electricity, which reflects both the quality/quantity aspects of electricity and the services provided by electricity. GTF classifies the degree of access to electricity based on supply and services provided multi-tiers shown in Table 4.

Table 4: SE4ALL multi-tier framework to measure electricity access for households (Sustainable Energy for All, 2013)

Attribute	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Services	-	Task light AND phone charging or radio	General lighting AND television AND fan	Tier-2 AND any low-power appliances	Tier-3 AND any medium power appliances	Tier-4 AND any higher power appliances
Peak available capacity (W)	-	>1 W	> 20 W/ 50 W	> 200 W/ 500 W	> 2,000 W	> 2,000 W
Duration (hours) -	-	> 4 hrs	> 4 hrs	> 8 hrs	> 16 hrs	> 22 hrs
Evening Supply (hours)	-	> 2 hrs	> 2 hrs	> 2 hrs	> 4 hrs	>4 hrs
Affordability	-	-	✓	✓	✓	✓
Formality (Legality)	-	-	-	✓	✓	✓
Quality (Voltage)	-	-	-	✓	✓	✓

On the energy access ladder, SHS is placed at the bottom to provide electricity for low power loads from Tier 1 and Tier 3 of the GTF. Then as the demand grows, mini-grid becomes a viable option and finally a point is reached when demand outgrows mini-grids so that extending the central grid can be considered. However, connectivity to grid does not ensure access to Tier 5 since grid supply can be intermittent and unreliable as seen in the case of Ghana where the national grid faces high levels of blackouts country-wide[26]. A properly functioning off-grid system can serve the communities better than an unreliable central grid.

To contextualise the multi-tier energy access ladder for Ghana, the services provided by electricity is classified into three broad categories of loads: household loads, communal loads and PUE loads.

1. Household loads: These include loads such as lighting, fan, etc. used within a household. The GFT multi-tier framework for household loads is modified for Ghanaian situation as shown in Table 5.

Table 5 Multi-tier classification of household loads

Tier	Appliances Rating (W)	Appliances
Tier 1 (T1)	<30 (very low power appliances)	Lighting, phone charging, radio
Tier 2 (T2)	30-150 (low power appliances)	Lighting, phone charging, radio, television, fan
Tier 3 (T3)	>150 (medium-high power appliances)	Lighting, phone charging, radio, television, fan, computer, air cooler, refrigerator, freezer, food processor, washing machine, water pump for domestic use, rice cooker, iron, hair dryer, toaster, micro-wave oven, air conditioner, space heater, water heater, electric cooking

2. Communal loads: Communal loads are those that serve the community as a whole including educational facility (e.g. school), healthcare facility (e.g. clinic), religious facility (e.g. church) and mini-enterprise.

3. PUE loads: This includes MSME, irrigation, agriculture, artisans, handicraft, agro-processing, aqua-culture for fisheries, food processing, income-generating activities and all other non-household, non-communal loads.

For the purpose of this report, the energy access ladder is captured as the following:

- When a community has household loads alone, it is served by SHS;
- Communal loads which require greater capacity are served by mini-utilities; and
- Mini-grids are only considered when PUE is involved since case studies have shown that income-generating activities powered by mini-grid is necessary to ensure enough demand and a reliable source of revenue for the developer.

To reflect the above, the load combinations are classified into three types as shown in

Table 6 with off-grid RES solution for each load combination type.

[26] The Consultants were informed during the Inception Mission in December 2014 that availability of grid in even Accra is 3 to 4 days in a week with a 24 hrs on, 12 hrs off is the cycle.

Table 6 Categorisation of load type and respective off-grid RES solution

Load type	Load combination	Off-grid RES system
Type 1 (L1)	Household (including T1, T2, T3)	SHS
Type 2 (L2)	Household (including T1, T2, T3) + Communal	SHS for household and mini-utility for communal
Type 3 (L3)	Household (including T1, T2, T3) + Communal + PUE	Mini-grid or hybrid*

**Further assessment would be needed to decide between mini-grid and hybrid systems based on site specific characteristics. This assessment is covered in Section 4.4.5.*

4.3 Explanation of parameters

This subsection lists the quantitative and qualitative parameters that will be used for the decision making process at each level. Their description and significance are provided along with the respective units of measurement.

4.3.1 Parameters at macro level

At macro level, the decision tool is aimed at arriving at a decision between grid extension and off-grid system using statistical information available readily through various sources. These parameters are displayed in the Annex 2. Distance parameter influences the cost of extending grid into a community. As distance grows, the cost increases until a certain cut-off point when it becomes cheaper to install off-grid systems. On the other, it has been decided that communities with population higher than 500 with road connectivity will receive grid connection in Ghana. Thus, distance, population and presence of road connectivity together are used to decide between grid and off-grid systems.

4.3.2 Parameters at meso level

The parameters at meso level capture site specific quantitative characteristics in order to decide the kind of off-grid RES system to choose, the system sizing and cost analysis. The significance of these parameters is briefly described below followed by a complete list of the parameters in Annex 2.

Technology parameters (2.1 – 2.2): The selection between solar PV or wind turbines depends on the available RE resources on the site such as global yearly irradiation levels and yearly average wind speed.

Power rating parameters (3.1 – 3.16): Solar or wind energy plant size are assessed based on the facility energy demands. The expected daily energy demand and the potential facility load profile parameter helps to estimate the potential installation size. This information is necessary to calculate the potential plant power rating (number of solar modules or wind turbines, battery size, etc.) required for the given facility energy demands and available solar or wind resources. On the other hand, the space availability is a relevant parameter too, for example, an understanding of available roof space or a nearby piece of land close to the facility where the installation could be located. This information is crucial as it could occur that the limiting size factor is the actual space availability.

Community spread and geographic parameters (4.1 - 4.5): The number of end users per unit area indicates the denseness or sparseness of the spread of the community. The geographic parameters describe in greater detail the site elevations and site extension plus the coverage of forest or water areas to determine how hostile the terrain is. Together, these data allow for estimation of the potential distribution line lengths which in turn dictates the cost of setting up mini-grid against having a hybrid sy-stem.

Community economic parameters (5.1): Parameters such as a typical household income level and expenditures in energy provide a more detailed idea regarding the affordability levels of the community and current family energy expenditure for example in kerosene lamps. This information is relevant to understand if an estimated tariff would be affordable for a given community and if not what would be the level of subsidy needed.

RES cost parameters (6.1 - 6.11): For a power plant the costs to be covered are various and vary depending on the project specifics. Typically the capital costs include items such as: PV modules/turbines, charge controllers, batteries, inverters, BOP, cabling, planning & design, labour, transport, etc. However, recurrent and O&M costs are considered as well such as: component replacements (battery/inverter replacements, etc.), maintenance activities, system operation, etc. On the other hand the potential benefits of having a RES system need to be estimated as well as the diesel fuel savings.

Recurring cost parameters (7.1 - 7.4): Off grid systems have certain system components that very likely will require replacement over the system lifetime, such as batteries (typical replacement period between 3-6 years, however depends on usage and technology employed) and inverters (typically between 7-10 years). Therefore these recurring cost parameters are being considered to provide a more realistic model.

Financial parameters (8.1 – 8.17): In order to calculate the levelised costs or rates of return of the RES system, parameters that reflect the financial trends of the country are utilised such as the inflation rates that affect for example the O&M costs in future years or the electricity escalation rates to estimate future sale revenues. On the other hand, the model takes into account the loan interest rates for rural areas which are relevant when calculating the rates of return of the investment. Therefore the financial parameters are being utilised to foresee the future cash flow balances for the potential investment in a solar PV or wind energy plant and therefore assess the viability of the investment. The financial parameters also include the definition of the loan interest rates, grace periods, maturity and grants in order to provide a realistic approach.

4.3.3 Parameters at micro level

The parameters at micro level are qualitative in nature that capture the socio-economic aspects of the local context as well as the enabling environment for setting-up the off-grid project. These are used to evaluate the social acceptability and financial viability of the off-grid RES project. Ultimately, these parameters will aid the project developers and the users in developing a mutually agreed upon business model. These parameters (described in Annex 2) are presented here:

- Willingness to pay
- Affordability or ability to pay
- Expected quality of service
- Interest of the community in the project
- Community readiness
- Presence of an NGO/ charity
- Level of local education/ exposure
- Payment options
- Potential for productive uses of energy
- Security of equipment
- Regulatory conduciveness
- Access to technical knowhow
- Supply infrastructure

The above parameters (though not exhaustive) are qualitative in nature and contextual, hence involve the subjectivity of the evaluator. The decision tool guides the evaluator/ user of the tool in making a final decision for a particular business model on the basis on the micro-level analysis.

4.4 The decision tool

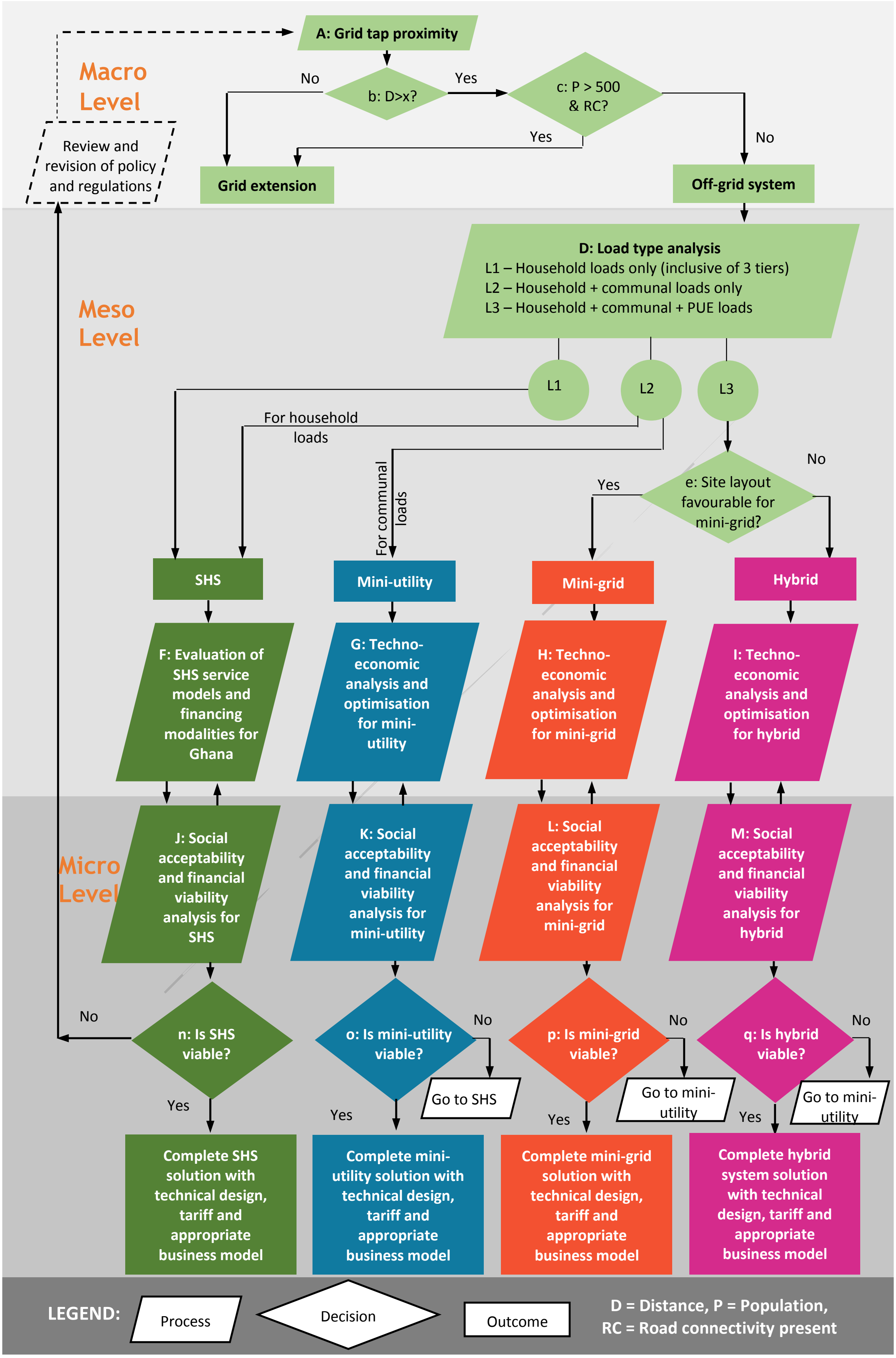


Figure 17 The decision tool flow chart

Figure 17 illustrates the flow of the decision making process from start to finish. For the sake of convenience in using the tool, all processes represented by parallelograms and decision triggers represented by diamonds are numbered in alphabetic order with processes in capital letters and decisions in small letters. The brief algorithm used for this decision tool is explained as follows:

1. Evaluate proximity to the grid tap. If "distance >x?" is "No" then select "Grid extension" as the most appropriate electrification option. If "distance>x?" is "Yes" then go to c. See Section 4.2.2 for detailed explanation.

2. In case of c, if "population>500 and road connectivity present?" is "Yes" then select "Grid extension". Otherwise select "Off-grid system." See Section 4.2.2 for detailed explanation.

3. Once off-grid system is selected, perform "Load type analysis" as the first step. If the load type is L1, then irrespective of whether it is T1, T2 or T3 loads, select SHS. If the load type is L2, then select SHS to serve household loads and mini-utility to serve communal loads. If the load type is L3, then go to e for further analysis between mini-grid and hybrid systems. See Section 4.2.3 for detailed explanation.

4. For SHS, evaluate service models and financing modalities (process F) that could be applicable to the community by using the recommendations made and the proposed service model on Chapter 2. The prospective users are surveyed to assess the kind of payment mode that is most acceptable to them (process J). This leads to the decision diamond "n: Is SHS viable?" If n is "Yes", then the complete SHS solution is arrived. If n is "No", then SHS is not a viable option and the policy and regulation need to be reviewed and revised to create a better enabling environment.

5. For mini-utility, carry out the techno-economic, social acceptability and financial viability assessment as specified in Section 4.4.4. This meso and micro level analysis will together help to decide "Is mini-utility viable?" If the answer is "Yes" then a complete mini-utility solution is reached including the technical design, tariff and business model. If the answer is "No" go to SHS.

6. If the load type is L3, then a further assessment needs to be carried out to see if the site is favourable for mini-grid or not as described in Section 4.4.5. If "e: Site layout favourable for mini-grid?" if yes then select mini-grid, else select hybrid.

7. For mini-grid, in similar manner to mini-utility, carry out the techno-economic, social acceptability and financial viability assessment as specified in Section 4.4.6. This meso and micro level analyses will together help to decide "Is mini-grid viable?" If the answer is "Yes" then a complete mini-grid solution is reached including the technical design, tariff and business model. If the answer is "No" go to mini-utility.

8. For hybrid, once a RES type is selected for particular areas within the community, carry out the techno-economic, social acceptability and financial viability analyses as per the methodology specified in Section 4.4.7. This meso and micro level analyses will together help to decide "Is hybrid viable?" If the answer is "Yes" then a complete hybrid solution is reached including the technical design, tariff and business model for each of the RES systems. If the answer is "No" go to mini-utility.

4.4.1 Introduction

The aim of the decision tool is to guide the user to make a decision between undertaking grid extension and installing an SHS, mini-utility, hybrid or mini-grid by interlinking the quantitative and qualitative parameters for a specific site with its specific circumstances. Each of the system types has advantages and disadvantages and hence, in order to decide which option is more suitable for a given community the decision tool is used.

The decision tool is a combination of a flow chart and excel spreadsheets. The flow chart in Figure 17 from the beginning to end starts requesting information to the user who has to assess and respond consequently to the questions defined along the chart. Each response will make the user advance a step further along the diagram that ultimately will help to decide what system type is more suitable for a given community. It has to be noted that the decision process defined in the decision tool takes into consideration different types of parameters along the chart including: grid proximity, community population, load types, site layouts, techno-economic aspects, social factors, etc. Therefore the aim of the tool is not only to guide the user in the decision of the type of system to install for a given site, but also to look at the techno-economic and social parameters.

The excel spreadsheets are tailored to supplement each step of the flow chart where actual values for the parameters are inputted that result in concrete outcomes to help make the decision. The input cells in the excel spreadsheets are represented by blue cells. These can be left with the default value, however if the user considers that the values are different they have to be inputted. On the other hand, the green cells represent the calculated results or decision outcomes based on the inputted information. The following sub-sections explain in greater detail with examples, what the decision tool aims for and what the outcomes are.

4.4.2 Grid Tap Proximity

The user when starting to use the decision tool will have to assess a set of various parameters, the first instance of which is the location of the community. As an example, for very remote communities where connectivity is challenging and transmission lines are considerably far, based on the decision diagram, the off-grid option would be preferable. Therefore, on the top of the diagram at macro level the user of the tool will have to respond to the question if the closest grid connection to the community is closer or further away than “x” km. For the scenario in which the site is closer than “x” km a grid extension is the outcome. Otherwise if the response is that the distance to the closest grid is greater than “x” then the diagram leads the user to a new question that focuses on the population of the community and presence of road connectivity. If the community has large population levels and there is road connectivity, then a grid extension is more suitable following the flow diagram outcome. In the decision tool, when the user has to decide if a community can be considered as small or big he will have to answer to the question if the population is greater or smaller than 500 and also has road connectivity. If both answers are yes, then the decision tool indicates that a grid extension would be recommended. However, if either the population is less than 500 or there is no grid connectivity, then an off-grid alternative will have to be assessed at the next stage.

4.4.3 Load type Analysis

Moving into the off-grid option (meso level) as the decision tool has disregarded the grid extension alternative new questions are asked in the flow diagram. When discussing off-grid options there are various choices possible: SHS, mini-utility, hybrid or mini-grid. Following the diagram at process D, the questions the user has to answer now are regarding the actual energy demands in the community assessed. The demands in the diagram are classified in three different groups depending on if they are for household, household & communal or household, communal and productive uses. If the electricity demand is just for households then the load is type “L1” and the diagram leads us to an SHS system. On the other hand if for example the community would consist of households, health centres and administration this means we have communal and household uses, which based on the diagram leads the user to a load type “L2” and the selected system will be SHS for households and mini-utility for the communal facilities. The third option would be the “L3” where PUE load is also present and the diagram leads us to a choice between mini-grid or hybrid system. Hence the user at this stage of meso level will assess for the given community, the type of demands the community has and based on the information a new decision has to be made between the different system types.

4.4.4 Techno-economic, social acceptability and financial viability analysis for mini-utility

Once the decision tool leads to mini-utility, further evaluation needs to be carried out to see if mini-utility is techno-economically viable, socially acceptable and financially viable. This involves analysis of both quantitative technical and financial parameters, and qualitative socio-economic parameters for a balance between top-down (supply side) and bottom-up (demand side) approach in order to reach an optimal solution. The user at this stage would use the tailored excel spreadsheet to facilitate specific site evaluation for the above parameters. The methodology followed for this evaluation using the excel spreadsheets is shown in Figure 18.

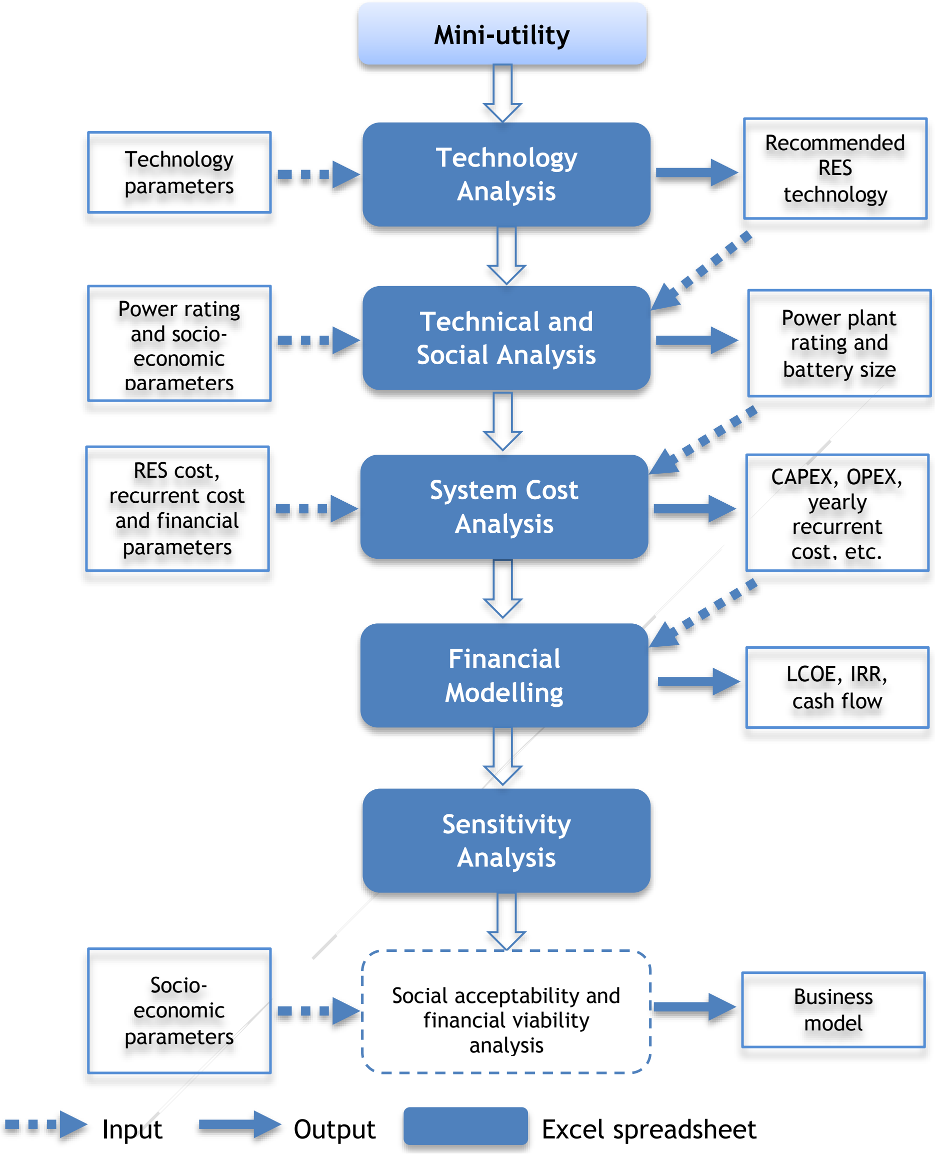


Figure 18 Mini-utility viability methodology

The tool is divided into 6 steps, which the user has to follow in the sequence laid out in Figure 18.

- The technology analysis tab will help the user to make a decision between using solar and wind energy or a hybrid of the two for powering the plant. The user in the tool has to input providing information regarding the yearly solar and wind resources available for the site. This data allows the tool to recommend what technology would be more suitable: wind turbines, solar PVs, a hybrid of both, or a situation where neither solar nor wind is suitable and hence another technology would have to be assessed.

- After the RES technology (solar/wind) has been chosen, the tool leads the user to the technical and social analysis tab. The technical and social analysis tab determines the technical details of the installation such as the plant size as well as a preliminary assessment of the community interest the project. The tool assesses the community interest in such a project before analysing the technical aspects[27]. The user has to input information regarding the community demands, interest and other technical power rating parameters (refer to Annex 2 for complete list of parameters) for the plant features, which allows the tool to estimate the approximate plant size.

- The system cost tab defines the CAPEX, OPEX, recurrent costs, grants, loan terms, interest rates, etc. In this part of the tool information regarding capital costs, recurrent costs and O&M costs has to be inputted by the user. Based on the input values, the tool determines the CAPEX, OPEX and recurrent expenditure. The user also has to provide information on the financial terms of the loan, grants, interest rates, etc. This information will then be used by the tool in the financial modelling section to assess the financial project viability.

- The financial modelling tab shows the yearly cash flows, profits, loan repayments, internal rate of return (IRR), LCOE, etc. for the given parameters defined. All the data provided previously by the user will allow the tool to undertake a complete financial modelling for the specific site where yearly cash flows are calculated, IRR estimated and LCOE obtained thus providing a view regarding the financial viability of the project based on the information inputted by the user.

- The sensitivity analysis tab is to evaluate the impact of variations in the initial assumptions made in the financial model on the estimated LCOE against the community affordability levels. The excel spreadsheet develops a sensitivity analysis where the uncertainty of several variables is analysed. This assessment is crucial as several parameters such as CAPEX, O&M, Recurrent Costs, Interest Rates or Grants can be difficult to estimate on preliminary stages. Therefore the tool develops a detailed sensitivity analysis showing the impact of the variation of this parameters on the LCOE and hence assessing the robustness of the business case against parameter modifications.

- Social acceptability and financial viability tab: The obtained financial results and sensitivity study developed will allow the user to move into the next step in the decision tool which involves "Social acceptability and financial viability". Based on the previously obtained financial results and LCOE, an indicative tariff should be set and payment options determined. Then a study has to be conducted through interviews or questionnaires, etc. to assess whether the customer is willing to pay the tariff level set, what payment option they are most comfortable paying and whether the tariff is affordable for them to decide if the system type is viable or not for the assessed community. Further, social parameter such as community cohesiveness, security, community readiness, etc. (full details in Annex 2) has to be assessed to develop an appropriate business model for the plant based on the recommendations made in Section 3.2. Note that assessing these social parameters involves a certain degree of subjectivity of the evaluator, as discussed in Section 4.3.3. If the "Social acceptability and financial viability" outcome is negative, based on the decision tool, a new system type has to be chosen.

Based on the outcome of the above process it can be decided if the selected system type is a viable solution for the community or not. Detailed explanation of how the user progresses through the excel tabs is provided in the Annex 3.

4.4.5 Site favourability analysis: Mini-grid vs hybrid

For sites with PUE loads, further analysis is carried out to decide whether mini-grid or hybrid RES makes better electrification option for the particular site. An excel spreadsheet facilitates this

---

[27] Although some social factors come into play at this stage of the decision making, further social-economic analysis necessary to determine social acceptability takes place at later stages.

analysis. The site layout of a specific community is crucial when deciding between a mini-grid and a hybrid RES system.

The developed tool allows the user to input different site characteristics such as community spread and geographic parameters (see ANNEX 2) that leads to a final decision between mini-grid and hybrid RES. Based on variables such as terrain properties, waterland areas, site extension, population density, etc. a solution is proposed by the tool. Detailed explanation is provided in Annex 4.

4.4.6 Techno-economic, social acceptability and financial viability analysis for mini-grid

After mini-grid has been selected following the site layout favourability analysis, similar methodological approach as that of mini-utility (as explained in Section 4.4.4.) is applied for techno-economic, social acceptability and financial viability analysis for mini-grid. The detailed use of the tool to arrive at an end solution is provided in Annex 5.

4.4.7 Techno-economic, social acceptability and financial viability analysis for hybrid

If hybrid is deemed to be more suitable option for a site than mini-grid then firstly, the user has to clearly demarcate the areas that will be served by SHS, mini-utility and mini-grid respectively within the community. Software such as the GIS-based tool currently developed by the MoP, or ViPOR may be utilised by the user to determine the optimum layout of the hybrid electrification system. For instance, in Figure 19, a concentrated cluster of end users, which include a few households and some PUE loads are served by a mini-grid plant; some scattered households in the left periphery of the village that are too far from the plant are served by individual SHS and lastly, a communal facility that is also at a good distance from the plant in the periphery of the village is served by a mini-utility.

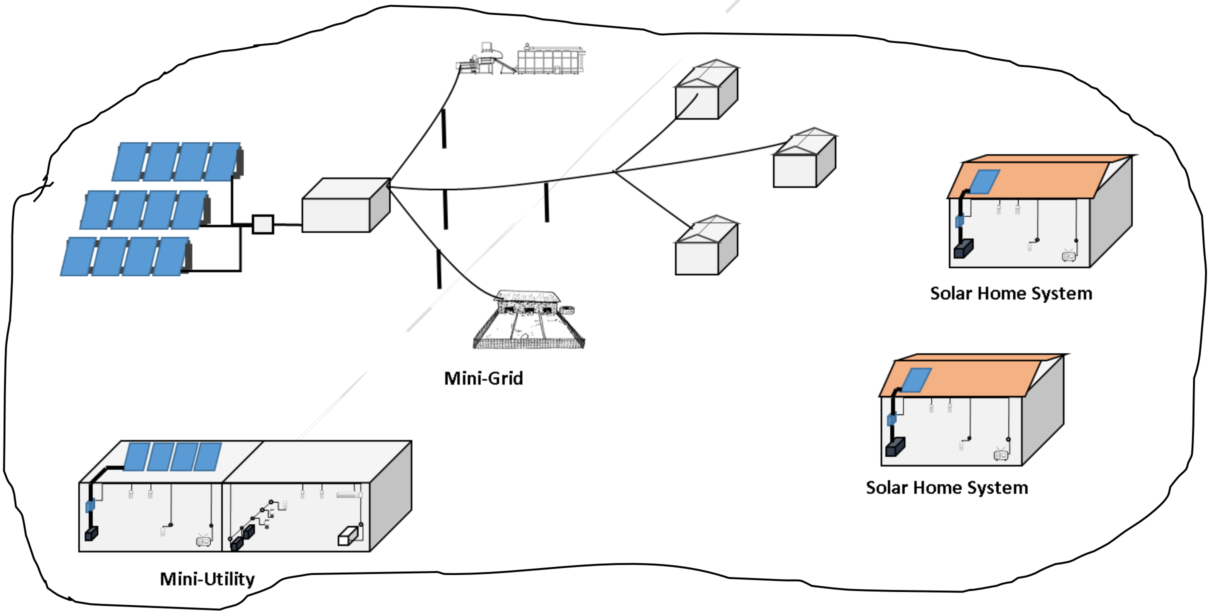


Figure 19 Layout of a hybrid system within a community

In such case, the techno-economic, social acceptability and financial viability analysis is carried out individually for each RES system type according to the respective methodology described for them previously. In the above example,

i) For the cluster of end users served by the mini-grid, carry out further viability assessment as specified for mini-grids in Section 4.4.6;
ii) For the scattered households served by SHS, evaluate financing modalities and service models and determine social acceptability as described earlier.

iii) For the facility served by mini-utility, carry out further viability assessment as specified for mini-utilities in Section 4.4.4.

4.5 The results matrix

Applying the above decision making tool, the appropriateness of each solution category (SHS, mini-utility, mini-grid and hybrid system) is presented in the results matrix in Table 7 using a list of quantitative and qualitative parameters.

Table 7 Determining the RES solution by application of the decision tool

Parameter	SHS	Mini-utility	Mini-grid	Hybrid
Distance of the community from the grid	As described in the previous sections, if distance of the community from the national grid tap is above x, it justifies a case for any of the off-grid system solution (SHS, mini-utility, mini-grid or hybrid systems) compared to extending the central grid to the community.			
Population and presence of road connectivity	Since it has been decided for Ghana that for communities with population above 500 that have road connectivity, grid will be extended, in such communities, even if the distance from the grid is above x, off-grid solutions are not considered in this report.			
Load type	SHS provide power for small household loads such as lighting, fans, phone, charging, and radio but inadequate to run appliances requiring higher power	Being larger in size than SHS mini-utilities are able to handle higher loads for larger facilities and communal loads such as hospitals that require power for refrigerating medicines, or to run electrical medical equipment	Mini-grids are able to service high power loads such as those required for productive uses but they are not cost-effective when load levels are very basic such as T1 and T2 loads	Hybrid comprises of any combination of SHS, mini-utility and mini-grids and their individual strengths and weakness in this category have been discussed
Terrain characteristics	SHS is preferable over mini-grids in sites characterised by difficult terrain such as steep slopes, dense forest cover and marshy lands	Since mini-utilities are standalone systems, difficult terrain does not incur high costs associated with distribution network	Costs increase significantly as terrain becomes rougher	Depending on the type of hybrid combination, this option maybe more suitable in sites characterised by a mix of gentle and difficult terrain
Geographic spread of the end users	SHS is the most cost-effective solution when users are scarcely spread	Similar to SHS, mini-utilities provide more cost-effective electrification for communal loads than mini-grids	Mini-grids are most cost-effective for densely populated sites sue to economy of scale but become too expensive when users are far	Hybrid systems can be most cost effective when a site has concentrated loads with some scattered users in the periphery

Parameter	SHS	Mini-utility	Mini-grid	Hybrid
			separated due to increase in the cost of distribution line	
Technology option	Obviously, SHS can only be powered by solar energy	Mini-utilities can use both wind and solar energy depending on the wind speed and solar irradiation level	Mini-utilities can use both wind and solar energy depending on the wind speed and solar irradiation level	Mini-utilities can use both wind and solar energy depending on the wind speed and solar irradiation level, except for the households served by SHS that is powered by solar energy
Community interest	Although less cost-effective in certain situations, SHS may be more socially acceptable to those end users who show a strong preference to manage their own system rather than the use of a shared resource (mini-grid) for electricity	For shared resources such as mini-utility, mini-grids and hybrid systems, the interest of the community in such a RES system project greatly affects the potential customer base for the project and hence revenue. As discussed in Chapter 3, often, villagers wrongly assume that solar powered electricity is not "real electricity" and can only be used for lighting and phone charging. Hence, in case of low community interest, social acceptability is low and thus the sustainability of the project is jeopardised. In this case, it is highly important to conduct workshops and other programmes to create awareness in the community about energy issues and the benefits of RES systems as a properly functioning RES system can provide better service in terms of quality and quantity than an unreliable grid. Having local authority of figure, church or NGO to motivate the villagers can be beneficial in this regard.		
Willingness to pay / affordability	Not applicable	When the LCOE and hence tariff is above the level of affordability or willingness of the customer to pay, the project becomes financially unviable. However, the tool performs a sensitivity analysis for a variation of ±30% in the values of financial parameters assumed in order to allow assessment of the robustness of the system. In case the LCOE is higher than affordable tariff, the tool proposes solutions described in Section 4.6.		
Community readiness*	Not applicable	The success of the respective RES project will also depend on how ready the community is to have such a project. The business model is adapted based on community readiness. For instance, community cohesion and dynamics will help determine to what degree the community must be involved in the development and operation of the project, which responsibilities must be handled by the community, and which ones by the developers, if the community can be expected to respect load limits, if not, what demand side management scheme must be implemented, whether there are local champions who can help promote PUE		

Parameter	SHS	Mini-utility	Mini-grid	Hybrid
		activities and energy awareness		

**Note: Community readiness includes community cohesion, organisational structure, presence of strong leadership, discipline, presence of local champions.*

4.6 Results analysis and solutions

The LCOE and affordability results obtained from the excel decision tool can potentially yield 2 scenarios: Scenario 1 where the LCOE is higher than the affordable tariff and Scenario 2 where the LCOE is lower than or equal to affordable tariff.

4.6.1 Scenario 1: LCOE > Community Affordable Tariff

It has to be noted that in the excel tool the value of the "Community Affordable Tariff" is defined by the user. Nevertheless under the current Ghanaian context the threshold value is normally set as the "unified tariff" (UT), as the initiative is led by the government.

Regarding Scenario 1 if the LCOE obtained with the tool is greater than the actual UT this means that the user would have to pay a higher price for the electricity. Therefore the user/responsible will have to make a decision based on the obtained results and assess potential actions which could minimise or even eliminate the gap between the LCOE and UT. The next paragraphs and Figure 20 provide an overview of potential approaches to reduce LCOE to an affordable level.

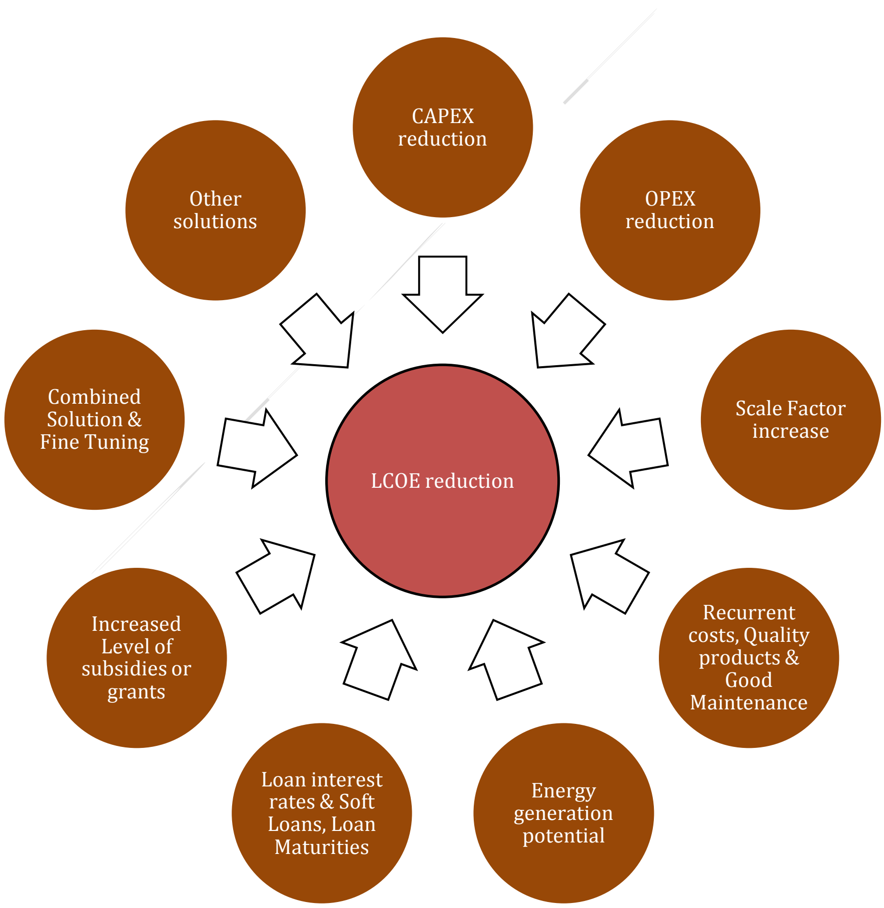


Figure 20 LCOE reduction strategies

- *Approach Number 1 - CAPEX reduction*: The CAPEX costs could be minimised through different strategies: changing the design layout for example using central architectures with inverters, employing more economical equipment such as polycrystalline PV modules instead of monocrystalline ones, using metal structures instead of concrete, etc.

- *Approach Number 2 - OPEX reduction*: Optimising the operational costs is a sensitive issue; it is a different alternative to reducing the yearly cost to manage the system. There are different alternatives: employment of local staff to undertake the operational activities, implementation of low maintenance components (for example utilising VRLA batteries instead of flooded types, etc.), optimising the number of times actual maintenance and operation activities are required.

  Nevertheless it has to be clearly noted that the OPEX reduction should not be taken too far otherwise this could translate in the reduction of the equipment lifecycle and therefore increased recurrent/replacement costs plus the reduced system energy performance leading to higher costs on the longer term and potential project failure.

- *Approach Number 3 – Scale factor increase*: The cost of a typical installation in USD/kW does normally reduce with the increase of the power plant size. Therefore, if a system has been sized for a specific part of a community, client, etc. and the LCOE is still too high, then a potential solution could be to assess if there are other potential members of the community interested in the RES project. This could lead to development of a larger RES plant that as consequence of the scale factor could be translated in a lower USD/kW cost and hence a lower LCOE.

- *Approach Number 4 – Recurrent costs, quality products and good maintenance*: The implementation of quality and reliable products, certified equipment etc. will reduce to risk of component failure minimising maintenance requirements and recurrent costs.

- *Approach Number 5 – Energy generation potential*: In order to maximise the energy output for a given installation, the utilisation of high efficiency equipment such as: inverters with high seasonal efficiencies (European efficiency), employment of MPPT inverters (maximum power point tracking inverters), proper cable sizing to reduce transport losses, shading reduction for PV panels or obstruction of wind turbines, regular plant maintenance, etc. The optimisation of this design factors will increase the energy generation potential output of a given installation and enhance the energy sales on a yearly basis.

- *Approach Number 6 – Loan interest rates and soft loans, loan maturities:* The financing terms for a given project can have an important effect on the actual LCOE. Hence, the typically higher interest rates for commercial loans make the viability of the project challenging. Therefore the assessment of financing alternatives such as soft loans with more accessible interest rates could be a decisive factor when the LCOE would like to be reduced, especially for large loans.

- *Approach Number 7 – Increased level of subsidies or grants*: Due to the capital intensiveness of the RES projects (first years), in order to be able to reduce the LCOE and hence the difference to the UT for Ghana, grants and subsidies of various forms can be considered.

- *Approach Number 8 – Combined solution and fine tuning*: The solutions proposed previously could be combined and fine-tuned in order to reduce the cost difference between the LCOE and UT as far as realistically possible. This means the user has to assess depending on the project characteristics and sensitivities the variables which have a greater impact on the project costs and which could help reduce the difference between the LCOE and UT.

- *Other solutions*: It has to be noted that depending on the project characteristics, RES technology, etc. other potential improvements or solutions could be proposed in order to reduce the LCOE. It has to be noted that as consequence of the project features, financial limitations or other constraints the LCOE and UT difference could not be reduced to the expected levels.

4.6.2 Scenario 2: LCOE <= Community Affordable Tariff

For this scenario the actual levelised costs of the standalone system would actually be lower than the actual UT. This means that grid parity has been achieved or even been overcome that is currently unlikely. However if in a future such a scenario would occur this would mean that the responsible entity, whether it is the government or private operator, would make a capital gain (comparing LCOE and UT) if the user is being charged the UT.

5 BIBLIOGRAPHY

(2015). *Aide Memoire. Scaling-up Renewable Energy Program in Ghana.*

Alliance for Rural Electrification. (2011). *Hybrid Mini-Grids For Rural Electrification: Lessons Learned.*

ARB Apex Bank. (Ghana Energy Development and Access Project, Solar Home Systems Project: Completion Report). *2014.*

Bank of Ghana. (2013). *List of Rural/Community Banks at January 2013.*

Bank of Ghana. (2014). *Quarterly Bulletin: July-September 2014.*

Bureau of Energy Resources, U.S. Department of State. (2013). *Investment Prospectus Framework for Ghana.*

Economic Consulting Associates. (2014). *Project Design Study on the Renewable Energy Development for Off-Grid Power Supply in Rural Regions of Kenya.*

ESMAP. (2000). *Mini-Grid Design Manual.*

European Union Energy Initiative Partnership Dialogue Facility. (2014). *Mini-grid policy toolkit. Policy and business frameworks for a successful mini-grid roll-outs.* European Union Energy Initiative Partnership Dialogue Facility.

Ghana CAP. (2012). *Ghana Sustainable Energy For All Action Plan.* Energy Commission, SE4All, UN Ghana.

Ghana Cooperative Credit Unions Association. (Data on Credit Unions for 2013). *2013.*

Haque, N. (2014). IDCOL Solar Home System Programme, Bangladesh.

INENSUS GmbH. (2011). The Business Model of Micro Power Economy.

International Monetary Fund. (2011). *Financial System Stability Assessment of Ghana.*

MF Transparency. (2012). *Country Survey of Ghana.*

Mondato. (2015). *MFS in Africa: Characteristics, Forecasts, Trends (2015).*

PWC. (2012). *Socio-economic study for mini-grid electrification of island communities.*

Restio Energy. (2014). *NuRa Case Study, STEPs Project.*

SE4ALL. (2014). High Impact Opportunity: Clean Energy Mini-Grids.

SE4ALL Ghana Action Agenda. (2015). *SE4ALL Ghana Action Agenda Summary.*

SE4All/ECREE. (2014). *Baseline Report for Ghanai.*

Sustainable Business Institute. (2013). *Scaling up Successful Micro-Utilities for Rural Electrification.*

Sustainable Energy for All. (2013). *Global Tracking Framework, v.3.*

TERI SRC. (2015). *Mini-Grid Workshop.* Bengaluru.

United Nations Foundation. (2014). *Microgrids for Rural Electrification: A critical review of best practices based on seven case studies.*

World Bank. (2010). *Rural Banking: The Case of Rural and Community Banking in Ghana.*

ANNEX 1: INSTALLATION AND MAINTENANCE LICENCE HOLDERS IN GHANA

No	Name of Company	Licence Number	Licence Issue Date	Licence Expiry Date	Address , Telephone and Email
1.	Enio Energy Gh. Ltd	EC/IM/12 -13-016	01/04/2014	31/03/2015	Address: P.O. Box 0239 Accra Tel No.: +7037271105 Email: vacquah@enioenergy.com
2.	Energiebau Sunergy Ghana Ltd	EC/IM/12 -13-017	01/04/2014	31/03/2015	Address: Springfield Road 3 Peduase Eastern Region Tel No.: 0289 913114/0244684948 Email: info@ energiebau-sunergy.com
3.	Solar World Africa Limited	EC/IM/12 -14-018	16/12/2014	15/12/2015	Address: No. 2 King Tackie Overpass, Kanda, P. O. Box AD 289 Adabraka, Accra Tel No.: 0274008000/0302902057 Email: enokumichael@yahoo.com
4.	Solarkiosk Ghana Limited	EC/IM/12 -14-019	16/12/2014	15/12/2015	Address: House/plot No. 9, Martey Tsuru, Spintex Road, Accra Tel No.: 0289553143 Email: patricia.safo@solarkiosk.eu
5.	Strategic Security Systems International Limited	EM/IM/R 1-04-15-003	27/04/15	26/04/2016	Address: P.O.BOX GP 13885, Accra. Tel: 0244116937 Email: info@3SIL.com.gh
6.	Emman Imex Enterprise	EC/IM/05 -15-021	14/05/2015	13/05/2015	Address: Emman Imex Enterprise, P.O.BOX MS 403, New Achimota, Accra Tel:0244233829
7.	Avior Energy Ghana Ltd	EC/IM/05 -15-022	14/05/2015	13/05/2015	Address: Avior Energy Ghana Ltd, P.O.BOX T.T75 Tema Newtown Tel:0205140518 Email:www.aviorenergy.com
8.	Trade Works Company Ltd	EC/IM/ R1 -05-15-023	14/05/2015	13/05/2015	Address: Trade Works Company Ltd, P.O.BOX AB 386, ABEKA Tel:0302403109 Website: www.appliancemasters.com.GH
9.	Axcon Group Ltd	EC/GWSL /05-15-67	14/05/2015	13/05/2015	Address: Axcon Group Ltd, 18555 Butterfield Blvd, Suite 1022, Morgan Hills, CA 95037 USA

10.	Deng Limited	EC/IM/R1-05-15-015	14/05/2015	13/05/2015	Address: Deng Limited, P.O.BOX AN 19996, Accra. Tel:0302257099/100 Email:www.dendltd.com
11.	Wilkins Engineering Limited	EC/IM/-05-15-024	14/05/2015	13/05/2015	Address: Wilkins Engineering Limited, Obonu Crescenot, NR .Hotel Adodo, North Kaneshie

ANNEX 2: PARAMETERS

Table 8 Macro level quantitative parameters

No	Parameter	Description/Note	Unit
1.1	Distance from grid	Distance of the community from grid tap	km
1.2	Population	Number of inhabitants of a particular site or community	pers
1.3	Road connectivity	Whether the community is connected by road or not	present or absent

Table 9 Meso level parameters

No	Parameter	Description/Note	Unit
Technical parameters			
Technology parameters			
2.1	Global solar irradiation	Sum of the direct beam plus the diffuse solar component on a horizontal surface	$kWh/m^2/day$
2.2	Average wind speed	A yearly average wind speed measured at 10m above the ground	(m/s)/year
Power rating parameters			
3.1	Expected daily energy demand	Total energy consumed for a typical average day. This includes assessment of not only current demand but also a forecast of likely future demand	kWh
3.2	Module performance degradation rate	PV modules have a yearly degradation rate which has to be considered when estimating the potential energy yields	%/year
3.3	Battery DoD	Battery depth of discharge (DoD). The parameter represents the maximum percentage of the maximum battery capacity which can be discharged without damaging the battery. The DoD varies depending on the type of battery	%
3.4	Battery roundtrip efficiency	The round trip efficiency of charging and discharging a battery	%
3.5	Days of autonomy	Number of days of autonomy required	days
3.6	Installation efficiency losses	The RES plant incurs several losses in its performance as consequence of different factors such as temperature, optical losses, dirtiness, panel tolerance, shadowing, etc. which needs to be	%

		considered as well	
3.7	Inverter CEC efficiency	Inverter performance across the range of the inverter's capacity. This gives you a better idea about the inverter's operating profile over the course of the day	%
3.8	Battery efficiency	Battery round trip efficiency from the process of charging and discharging	%
3.9	Other battery losses	Other energy losses taking place in the battery such as self-discharge, Joule effect etc.	%
3.10	Battery size	The energy storage capacity of the battery	kWh
3.11	System performance degradation rate	The system performance of certain RES technologies such as solar PV tends to have a progressive loss of performance over the years	%/year
3.12	Module efficiency	The efficiency of the PV module at STC conditions	%
3.13	PV power plant rating	The nominal power rating of the PV installation	kWe
3.14	Wind power plant rating	The wind power size of the wind plant at 6m/s wind speed	kWe
3.15	Estimated yearly electricity supply	The electricity supplied by the system on yearly basis	kWh
3.16	Distribution line efficiency losses	% of lost energy from total as consequence of the Joule effect when electricity is transmitted	%
Community spread and geographic parameters			
4.1	Population density	Number of people per unit area	pers/km^2
4.2	Site extension	Site area	km^2, hectares
4.3	Terrain steepness	Parameter to indicate the terrain steepness	flat, medium or steep
4.4	Number of main clusters	Parameter to indicate the number of main clusters for a given community	-
4.5	Waterland	Parameter indicating if the clusters are separated by waterland	-
Economic parameters			
Community economic parameters			
5.1	Community affordable tariff	The electricity tariff which is affordable for the assessed community	USD/kWh

System cost parameters			
6.1	PV Module/Turbine cost	PV module or wind turbine costs	USD/Wp
6.2	Inverter	Electronic device or circuitry that changes direct current (DC) to alternating current (AC)	USD/Wp
6.3	Mounting structure	Engineered frame made of metal, concrete or wood materials designed to mount *PV* modules	USD/Wp
6.4	Battery cost	Cost of the battery banks	USD/kWh
6.5	Control panels and wiring	Charge controllers, MCBs, fuses, cabling, etc.	USD/Wp
6.6	Appliances	Light fittings, plugs, etc.	USD/Wp
6.7	Others	Insurance, profit margins, contingency, etc.	USD/W
6.8	O&M costs	The operation and maintenance costs would include operation, maintenance, taxes, insurance, maintenance, recurring costs (battery or inverter replacement, etc.)	USD/Year
6.9	CAPEX	Capital expenditure	USD
6.10	OPEX	Operational expenditure	USD
6.11	Electricity tariff	The electricity tariff that the users will pay	USD/kWh
Recurring cost parameters			
7.1	Inverter replacements lifetime	Number of replacements of the inverter over the installation lifetime	Replacements / lifetime
7.2	Battery replacements lifetime	Number of replacements of the battery bank over the installation lifetime	Replacements / lifetime
7.3	Other replacement costs lifetime	Number of replacements of other equipment during the installation lifetime	Total cost over lifetime (USD)
7.4	Total yearly recurrent costs	The total recurrent costs per year	USD/Year
Financial parameters			
8.1	Electricity tariff	Tariff at which is electricity is sold	USD/kWh
8.2	Loan interest rates	Typical loan interest rates for commercial banks in rural kind of areas	%/year
8.3	General inflation rate	Country national average inflation rate over recent years	%/year
8.4	Yearly tariff escalation rate	The average annual escalation rate of tariff over the last years	%/year

8.5	Yearly O&M costs escalation rate	The average annual escalation rate of the O&M costs in the Ghanaian context	%/year
8.6	Yearly recurring cost escalation rate	The average annual escalation rate of component replacements over the last years in Ghana	%/year
8.7	Economic/financial evaluation life period	The economic evaluation of an RES investment typically could be the life period of the installation however it could be focused on the loan terms	Years
8.8	Grant	Represent non-repayable funds disbursed by governments or other organisation for a particular purpose	USD
8.9	Loan grace period	The period of time where no loan repayments have to be done without any penalty or loan suspension	Years
8.10	Loan interest rate	The interest fees paid on monthly or yearly basis on the remaining pending loan value to be repaid	%
8.11	Collection rate	Represents the percentage of reimbursement collected from the total amount of the energy sales	%
8.12	Loan maturity	The period of time in which the total amount of the loan has to be repaid	Years
8.13	Loan repayment	Loan amount pending still has to be repaid	USD
8.14	Yearly system costs	Represent the yearly system costs of adding the O&M and recurrent system costs	USD
8.15	Net profits	Represent the yearly gains from subtracting the yearly running costs of the installation to the yearly electricity sales	USD
8.16	Internal rate of return (IRR)	The IRR is used to evaluate the attractiveness of a project or investment and is the interest rate at which the net present value of all the cash flows from an investment are equal zero	-
8.17	Levelised Cost of Energy (LCOE)	Represents the cost of electricity produced by the energy system. The LCOE is obtained accounting for all the plant units expected lifetime costs CAPEX, OPEX, loans, etc. which are then divided by the	USD/kWh

		lifetime expected energy output	

Table 10 Micro level parameters

No	Parameter	Description/Note
9.1	Willingness to pay	Whether a user expresses willingness to pay a benchmark tariff level for electricity services provided
9.2	Ability to pay	Based on current household/facility expenditure in energy (on dry cell battery, genset, kerosene, firewood for heating water, charcoal for press iron, etc.), their typical income level, and prevailing economic activities
9.3	Expected quality of service	Supply duration, evening hours supply, services provided by electricity (for T1, T2 or T3 or PUE, etc.)
9.4	Interest	Whether the user is interested in receiving electricity, preference to manage own system (such as SHS) or be served by a common power source (mini-grid)
9.5	Payment options	Frequency of fee collection, bulk or periodic payment, post-paid or prepaid, etc.
9.6	Productive use of energy services	What businesses could potentially be developed on the arrival of electricity?
9.7	Security	Risk of theft or vandalism, clashes among rival groups or rebel factions, or other factors that may pose a security threat to the employees, etc.
9.8	Regulatory conduciveness	Regulatory and policy framework for decentralised RES development. Does subsidies and premiums exist to support RES project? What are the mechanisms of entry for private sector (first-come-first serve? auctions? etc.), fiscal incentive, public financing, procedural time to permit and start operating a new RES project, no. of agencies to go through, can the operator charge tariff different from the national tariff level?, etc.
9.9	Access to technical knowhow	Does a prospective project developer have easy access to technical knowhow to start an off-grid RES project?
9.10	Supply infrastructure	Supply of spare parts, batteries or other parts for repairs and replacements, etc.
9.11	Community readiness	Community cohesion, organisational structure, presence of strong leadership, discipline, etc.
9.12	Presence of NGOs, local institutions such as church	Presence and ability of any local institution/committee that can help mobilise the development of PUE activities in the community
9.13	Level of local education/exposure to technology	Level of education/exposure to technology of the locals to assess whether the project operator can train and hire local people for daily O&M activities, which can be cheaper or use their own properly trained employees for this purpose, which can be more expensive

ANNEX 3: TECHNO-ECONOMIC, SOCIAL ACCEPTABILITY AND FINANCIAL VIABILITY ANALYSIS FOR MINI-UTILITY

Technology analysis

The technology tab requires the user to input the values of technology parameters, i.e average global horizontal solar irradiation level (GHI) and average wind speed for the site as defined in Annex 2. When these parameters are inputted, a result is generated recommending the more suitable resource technology. To illustrate with an example, the technology simulation panel can be observed in **Error! Reference source not found.** where for a GHI of 4kWh/m^2/day and an average wind speed of 5.0m/s the "Recommended RES Technology" is "Solar Photovoltaics". For clarity the result is also shown graphically in the RES Technology Matrix where the function point named "Current Site" reflects the values of GHI and average wind speed.

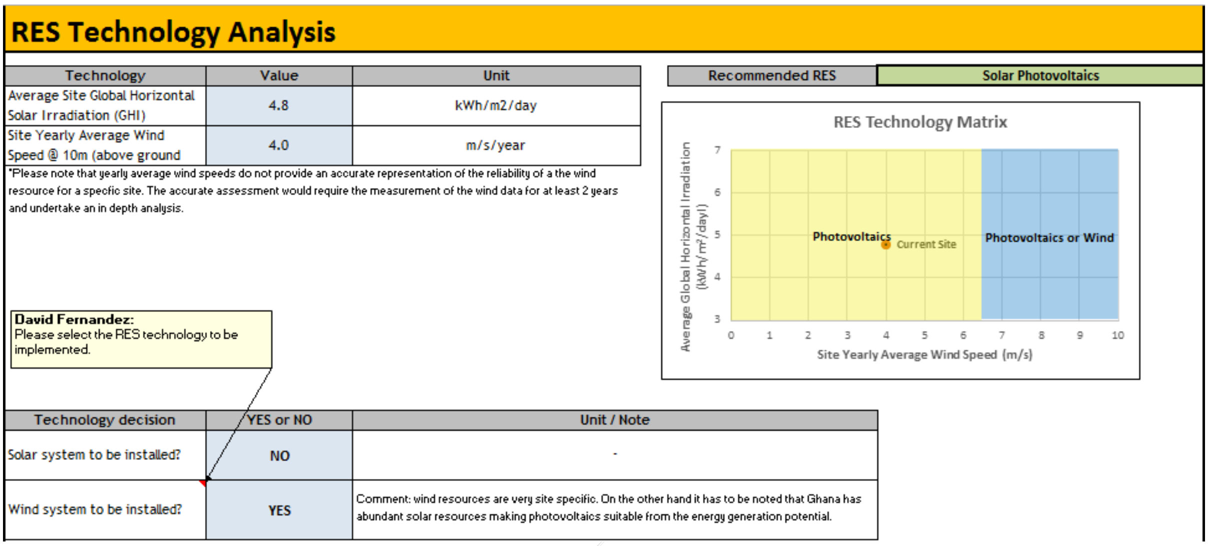


Figure 21 Simulation panel - Technology analysis

Please note that the recommended technology has to be specified in the "Technology Decision" table again in the bottom left of the simulation panel. The reason for creating this additional input is to allow the user to choose between solar or wind technology based on criteria different than the one presented in the excel tab. In his example, solar is the recommended technology based on the input values for GHI and average wind speed. Nevertheless as shown in the "Technology Decision" table of the simulation panel, a final decision has to be made by the user on whether to select: PV, Wind or both. Obviously the user can follow the suggestion provided by the calculation tool or not (in this case the recommendation is a PV system). Further calculations in the following steps in the worksheets will depend on the technology choice made at this stage.

Technical and social analysis

The technical and social analysis analysis tab will define the size of the potential PV plant, wind plant or their hybrid for the mini-utility depending on the selected RES technology in the Technology Analysis Tab. It will also make a preliminary assessment of community interest, willingness to pay and affordability. Firstly, the user has to specify the level of community interest (no interest, moderate or high interest), the level of willingness to pay (no interest, moderate or high interest) and input an estimated affordable tariff. If either the community interest of willingness to pay is low, the tool firstly recommends creating awareness programme in the community to raise the level of interest/willingness to pay. Otherwise, the tool recommends carrying on with further technical and financial analysis.

Moving further with the technical analysis, the user has to input the expected daily energy demand for the facility and other power rating parameters such as battery depth of discharge, battery and inverter efficiency, etc. (please note all these parameters are defined in Annex 2). The spreadsheet already defines default values for these parameters, which the user can change according to requirement. An example is illustrated in the simulation panel in Figure 22 where the battery size, PV power plant rating and electricity generated on a yearly basis are estimated.

Mini-Utility Technical & Social Analysis

Input Value	
Result	

Energy Demand	Value	Unit / Note
Expected daily energy demand	20.0	kWh/day

Battery Parameters	Value	Unit / Note
Battery DoD	65.0%	%
Days of autonomy	3	days
Battery efficiency	80.0%	%
Other battery losses (self discharge, joule effect etc.)	4.0%	%
Battery size	130.64	kWh

Solar PV	Value	Unit / Note
Applicable	YES	
Module efficiency	15.0%	%/year
System performance degradation rate	1.0%	%/year
Installation efficiency losses (temperature factor, optical, dirtiness, panel tolerance, cable, shadowing, etc.)	25.0%	%
Inverter seasonal efficiency	92.0%	%
PV Power Plant Rating	6.67	kWe
Estimated yearly electricity supply	7,300	kWh/year

Comment: Panel inclination factors have been dismissed based on Ghana's Low

Wind Power Plant	Value	Unit / Note
Applicable	NO	
Capacity Factor	15.0%	
Installation efficiency losses (mechanical losses, transport losses, etc.)	10.0%	%
Inverter seasonal efficiency	92.0%	%
Wind Power Plant Rating	0.0	kWe
Estimated yearly electricity supply	0	kWh/year

Social Parameters	Value	
Community interest in RES project	Moderate-High Interest	
Community willingness to pay	Moderate-High Interest	
Estimated Community Affordability Tariff	7	USD/kWh
Community project rating	Technical and Financial Feasibility Study recommended	

Figure 22 Simulation panel - Multi-utility technical and social analysis

System costs

The potential plant ratings calculated in the previous tab is used to estimate installation costs of the different system components, loan requirements, interest rates, etc. (Please note that the parameters utilised here are described in Annex 2.)

The example simulation panel can is shown in Figure 23 where the table "Solar/Wind Cost Indicators" estimates the CAPEX of the installation. Please note that the cost is based on the USD/W cost benchmark for the different installation components. The user, as in previous cases, could vary the default values (cells in blue). Similarly in the "Grants, Loan & Equity" table on the top-right of the simulation panel, the loan terms such as grants, upfront contributions, loan maturities, interest rates or grace periods can be inputted. These loan terms would vary depending on the rural bank, loan amount etc. and would have to be inputted by the user. The loan value is already a result from subtracting the grants and upfront contributions to the total installation costs.

In addition, as seen in the bottom half of the simulation panel, the user also has to define values for other parameters such as the electricity tariffs, collection rates, O&M costs, recurrent costs etc. as these information is crucial to evaluate in viability of the project in the next tab where the financial modelling is undertaken.

Mini-Utility Costs

Input Value	
Result	

Solar/Wind Cost Parameters	Value	Unit	Unit
PV Module/Turbine cost	5.2	USD/W	USD 34,667
Mounting structure	0.4	USD/W	USD 2,667
Control Panels & Wiring	0.2	USD/W	USD 1,333
Installation, Labour..	0.15	USD/W	USD 1,000
Inverter	0.3	USD/W	USD 2,000
Others (insurance, profit margins, contingency,	0.25	USD/W	USD 1,667
Battery cost	700	USD/kWh	USD 91,451
CAPEX	USD 134,784		

Grants, Loan & Equity	Value	Unit / Note
Grant	15,000	USD
Upfront contributions	0	USD
Loan value	USD 119,784	USD
Loan Maturity	7	Years
Loan Grace Period (Note: min 1 year)	2	Years
Loan interest rate	17.00%	%

Lifecycle	Value	Unit / Note
Economic/Financial Evaluation Life period	20	Years

Recurrent Costs	Number replacements	Unit / Note
Inverter replacements	1	Replacements / lifetime
Battery replacements	3	Replacements / lifetime
Other Recurrent Costs	**Cost**	**Unit / Note**
Other replacement costs lifetime	0	Total cost over lifetime (USD)
Total yearly recurrent costs	13,818	USD/Year

Electrical Tariffs	Value	Unit / Note
Electricity Tariff	7	USD/kWh
Yearly Tariff Escalation rate	4.0%	%
Collection rate	95.0%	%
Typical Affordable Tariff	5	USD/kWh

O&M	Value	Unit / Note
O&M costs	400	USD/Year
Yearly O&M costs escalation rate	4.0%	%/year

Figure 23 Simulation panel – Mini-utility system costs

Financial modelling

For this tab no information has to be inputted by the user as all the information requirements have already been defined previously. The output is the cash flow, IRR and LCOE to show the financial viability of the project (please note the sensitivity study has not been completed yet and same applies for the affordability parameters). This tool allows for iteration and adjustment of the level of grant/subsidy necessary for a specific system if the LCOE is too high to be afforded by a specific community.

An example of the developed financial simulation panel is illustrated in Figure 24. The progression of the energy consumption for the given mini-utility from year 0 to year 20 can be observed based on the yearly capacity loss of the installation as consequence of the ageing and hence system performance loss of the installations (degradation rate factor, please refer to Annex 2 for further details). On the other hand the fuel escalation rates are considered to estimate future electricity rates and hence sales, the same principles are applied for the O&M and recurrent costs where the respective inflation rates are taken into account. Additionally, the cash flow analysis shows the loan repayment process and interest fees paid. The yearly net profit is given to observe if the yearly electricity sales are sufficient to offset the system costs and loan repayments. Finally, in the bottom left section of the panel, the IRR and LCOE are shown that are indicators of the financial feasibility of the investment.

	Result								
Year	0	1	2	3	--------	17	18	19	20
Tariff Escalation Factor	1.00	1.04	1.08	1.12		1.95	2.03	2.11	2.19
O&M Escalation Factor	1.00	1.04	1.08	1.12		1.95	2.03	2.11	2.19
Component Replacement Escalation Factor	1.00	1.11	1.16	1.20		2.09	2.17	2.26	2.35
Loan Repayment Pending ($/Year)	109,173	109,173	109,173	93,609		0	0	0	0
Loan repayments ($/Year)		0	0	34,124	--------	0	0	0	0
Loan interest rates ($/Year)		18,559	18,559	18,559		0	0	0	0
Electricity consumption (kWh/Year)	0	7,300	7,227	7,155		6,216	6,153	6,092	6,031
Electricity Sales ($/Year)	0	50,487	51,981	53,520		80,515	82,898	85,352	87,878
O&M costs ($/Year)	0	400	433	450		779	810	843	876
Recurrent system costs ($/Year)	0	14,162	16,408	17,065	--------	29,550	30,732	31,962	33,240
Yearly costs ($/Year)	0	14,562	16,841	17,514		30,329	31,543	32,804	34,116
Net Profits ($/Year)	0	35,925	35,140	36,005		50,185	51,355	52,547	53,762
Cash Flow ($/Year)	-269,181	35,925	35,140	36,005	--------	50,185	51,355	52,547	53,762
IRR	14%								
Levelised Cost of Energy (LCOE)	5.64	$/kWh							

Figure 24 Simulation Panel - Financial model mini-utility

Sensitivity analysis

The tool has a sensitivity analysis tab in order to assess the impact on the LCOE if a specific variable has been over or underestimated by up to ±30% to what has been initially assumed. The sensitivity study is evaluated against following:

- ±30 CAPEX variations
- ±30 O&M cost variations
- ±30 Recurrent cost variations
- ±30 Loan interest rate variations
- ±30 Grant variations

This analysis provides a better understanding regarding the level of robustness of the business case against the underlying assumptions used. The aim is to evaluate to what extend changes from initial assumptions in the financial model would impact the estimated LCOE against the community affordability levels. Please note the results are presented in both in tabular (see Table 11) and graphical forms (see Figure 25**Error! Reference source not found.**).

Table 11 Sensitivity analysis – Mini-utility

SENSITIVITY ANALYSIS

Sensitivity analysis against CAPEX variations		
Variation (%)	CAPEX (USD)	LCOE (USD/kWh)
		4.2
-30.00%	99,290	4.0
-20.00%	113,474	4.3
-10.00%	127,659	4.6
0.00%	141,843	4.8
10.00%	156,027	5.1
20.00%	170,212	5.4
30.00%	184,396	5.7

Sensitivity analysis against O&M cost variations		
Variation (%)	O&M Costs (USD/Year)	LCOE (USD/kWh)
		4.18
-30.00%	280	4.15
-20.00%	320	4.16
-10.00%	360	4.17
0.00%	400	4.18
10.00%	440	4.19
20.00%	480	4.20
30.00%	520	4.21

Sensitivity analysis against Recurrent Cost variations		
Variation (%)	Recurrent Costs (USD/Year)	LCOE (USD/kWh)
		4.2
-30.00%	9,894	4.2
-20.00%	11,307	4.5
-10.00%	12,721	4.8
0.00%	14,134	5.1
10.00%	15,547	5.4
20.00%	16,961	5.8
30.00%	18,374	6.1

Sensitivity analysis against Loan Interest Rate variations		
Variation (%)	Loan Interest Rate (%)	LCOE (USD/kWh)
		4.2
-30.00%	11.9%	3.8
-20.00%	13.6%	3.9
-10.00%	15.3%	4.0
0.00%	17.0%	4.2
10.00%	18.7%	4.3
20.00%	20.4%	4.5
30.00%	22.1%	4.6

Sensitivity analysis against Grant variations		
Variation (%)	Grant (USD)	LCOE (USD/kWh)
		4.2
-30.00%	10,500	4.3
-20.00%	12,000	4.2
-10.00%	13,500	4.2
0.00%	15,000	4.2
10.00%	16,500	4.2
20.00%	18,000	4.1
30.00%	19,500	4.1

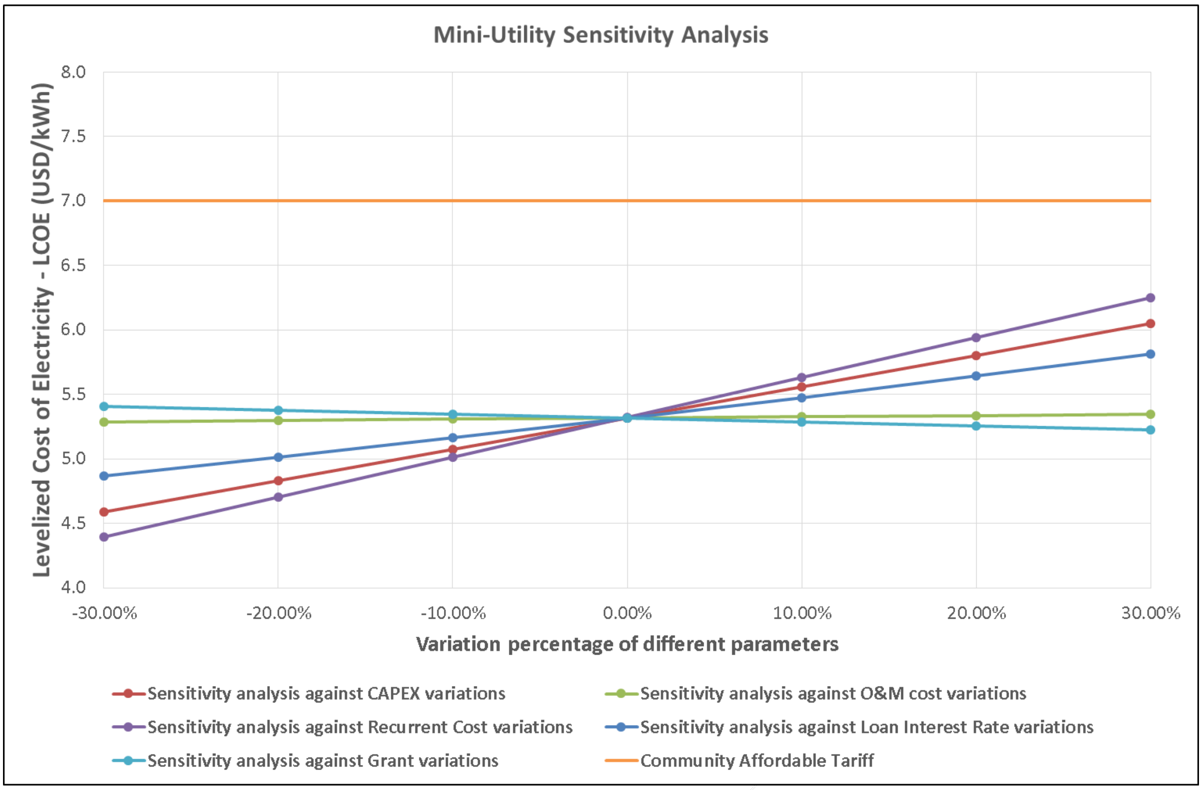


Figure 25 Sensitivity analysis - Mini-utility

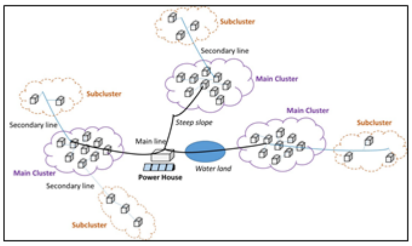
ANNEX 4: SITE LAYOUT FAVOURABILITY

The site layout of a specific community is crucial when deciding between a mini-grid and a hybrid system. The developed simulation panel allows inputting different site characteristics (see Figure 26) leading to a final decision. A flow diagram has been added below showing the decision process in Figure 27. Based on variables such, terrain properties, waterland areas, site area, population density, etc. a solution is proposed by the tool.

Site Layout Analysis - MG vs HY

Input Value	
Result	

Site Layout Parameters	Value/Response	Unit
Terrain Stepness	Flat (2˚<)	˚
Clusters separated by waterland	NO	
Site Extension	2	km2
Population density	Medium (70-130pers/km2)	pers/km2
Total Population	400	pers
Road Connectivity to Site?	NO	pers
Number of main clusters	3	units
% "Feeder Line Length" against "Total Line Length"	40.0%	%
Estimated Main Lines Length (radial network)	2.4	Km
Estimated Feeder Lines Length	1.0	Km
Total Line Length	3.4	Km
System Type	Mini-Grid	



Author:
Please note this result is based on the inputted information on the related tabs including the tab "MG vs HY Technical Analysis".

Figure 26 Simulation panel - Site layout analysis mini-grid vs hybrid

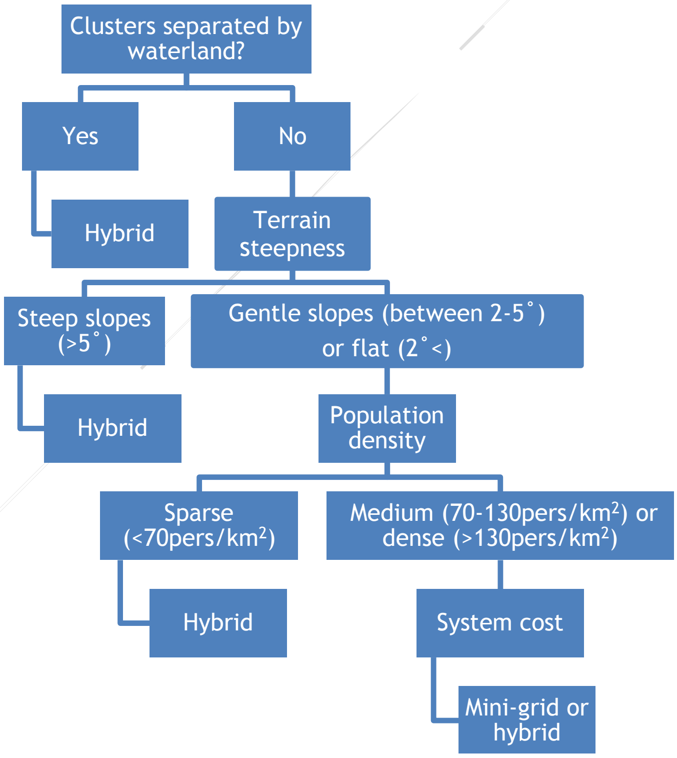


Figure 27 Decision chart mini-grid vs hybrid

ANNEX 5: TECHNO-ECONOMIC, SOCIAL ACCEPTABILITY AND FINANCIAL VIABILITY ANALYSIS FOR MINI-GRIDS

Technology analysis

The same analysis is undertaken for mini-grid as was done for mini-utilities.

Technical analysis

The same analysis is undertaken for mini-grid as was done for mini-utilities. The main difference lies in the fact that the inputs specific to mini-grid system has to be taken (see Annex 3, Figure 28 for clarity).

Mini-Grid / Hybrid Technical Analysis

Input Value	
Result	

Social Parameters	Value	
Community interest in RES p	Moderate-High Interest	
Community willingness to pa	Moderate-High Interest	
Estimated Community Affordability Tariff	7.0	USD/kWh
Community project rating	Technical and Financial Feasibility Study recommended	

System Type	Hybrid vs Mini-Grid
Battery size reduction with minigrid against hybrid system	15.0%
Plant power rating reduction with minigrid against hybrid	25.0%

System Type	Hybrid	Mini-Grid	
Energy Demand	**Value**		**Unit / Note**
Expected daily energy demand	161.4		kWh/day

System Type	Hybrid	Mini-Grid	
Battery Parameters	**Value**		**Unit / Note**
Battery DoD	60.0%		%
Days of autonomy	3		days
Battery roundtrip efficiency	80.0%	80.0%	%
Other battery losses (self discharge, temperature etc.)	2.0%	2.0%	%
Battery size	**1119.1**	**931.0**	kWh

System Type	Hybrid	Mini-Grid	
Solar PV	**Value**		**Unit / Note**
Applicable (defined in "RES Technology & Load Analysis" tab)	**NO**		
Module efficiency	15.0%		%/year
Module performance degradation rate	1.0%		%/year
Installation efficiency losses (temperature factor, optical, dirtiness, cable losses, panel tolerance, shadowing, etc.)*[1]	25.0%		%
Distribution Line Efficiency Losses*[2]	0.0%	3.0%	%
Inverter CEC efficiency	92.0%	94.0%	%
PV Power Plant Rating	**0.0**	**0.0**	kWe
Estimated yearly electricity supply	**0**	**0**	kWh/year

Comment: *[1] Panel inclination factors have been dismissed based on Ghana's Low Latitude (almost on the equator).

Comment: *[2] If the system has a distribution line the losses have to be included. For solar home systems or mini-utility no distribution is included thus no losses have to be taken into account.

System Type	Hybrid	Mini-Grid	
Wind Power Plant	**Value**		**Unit / Note**
Applicable (defined in "RES Technology & Load Analysis" tab)	**YES**		
Capacity Factor	15.0%		%
Installation efficiency losses (mechanical losses,transport losses, etc.)	10.0%		%
Inverter seasonal efficiency	92.0%	94.0%	%
Wind Power Plant Rating	**67.7**	**66.3**	kWe
Estimated yearly electricity supply	**58,926**	**58,926**	kWh/year

Figure 28 Simulation panel - Mini-grid vs hybrid technical and social analysis

System costs

The same analysis is undertaken as for mini-utility. The input parameters specific to mini-grid must be taken. On the other hand the distribution line costs have to be defined into the cost sheet (please refer to Figure 29 for clarity).

Mini-Grid / Hybrid Costs

Input Value	
Result	

System Type	Hybrid vs Mini-Grid
Scale cost factor minigrid against hybrid system	5.0%

System Type	Hybrid	Mini-Grid		Hybrid	Mini-Grid
Solar/Wind Cost Parameters	Value		Unit	Totals (USD)	
PV Module/Turbine cost	5.2		USD/W	USD 34,667	USD 33,952
Mounting structure	0.4		USD/W	USD 2,667	USD 2,612
Control Panels & Wiring	0.2		USD/W	USD 1,333	USD 1,306
Installation, Labour..	0.15		USD/W	USD 1,000	USD 979
Inverter	0.3		USD/W	USD 2,000	USD 1,959
Others (insurance, profit margins, contingency, etc.)	0.25		USD/W	USD 1,667	USD 1,632
Battery cost	500		USD/kWh	USD 65,322	USD 54,662
Network Line Cost Parameters	Value	Value	Unit	Totals (USD)	
Network line infrastructure cost (including cable, poles,	0	5	USD/m	$0	$11,900
			CAPEX	USD 108,655	USD 109,002

Grants, Loan & Equity	Value	Unit / Note
Grant	15,000	USD
Upfront contributions	0	USD
Loan value	USD 93,655	USD
Loan Maturity	7	Years
Loan Grace Period (Note: min 1 year)	2	Years
Loan interest rate	17.00%	%

Lifecycle	Value	Unit / Note
Economic/Financial Evaluation Life period	20	Years

Recurrent Costs	Number replacements	Unit / Note
Inverter replacements	1	Replacements / lifetime
Battery replacements	3	Replacements / lifetime
Other Recurrent Costs	Cost	Unit / Note
Other replacement	0	Total cost over lifetime (USD)
Total yearly recurrent costs	9,898	USD/Year

Electrical Tariffs	Value	Unit / Note
Electricity Tariff	7	USD/kWh
Yearly Tariff Escalation rate	4.0%	%
Collection rate	95.0%	%
Typical Affordable Tariff	5	USD/kWh

O&M	Value	Unit / Note
O&M costs*	400	USD/Year
Yearly O&M costs escalation rate	4.0%	%/year

*The O&M costs for mini-grid & hybrids have been assumed the same

Figure 29 Mini-grid vs Hybrid System Costs Panel

Financial modelling

The same analysis is undertaken as for the mini-utility.

Sensitivity analysis

The same analysis is undertaken as for mini-utility.